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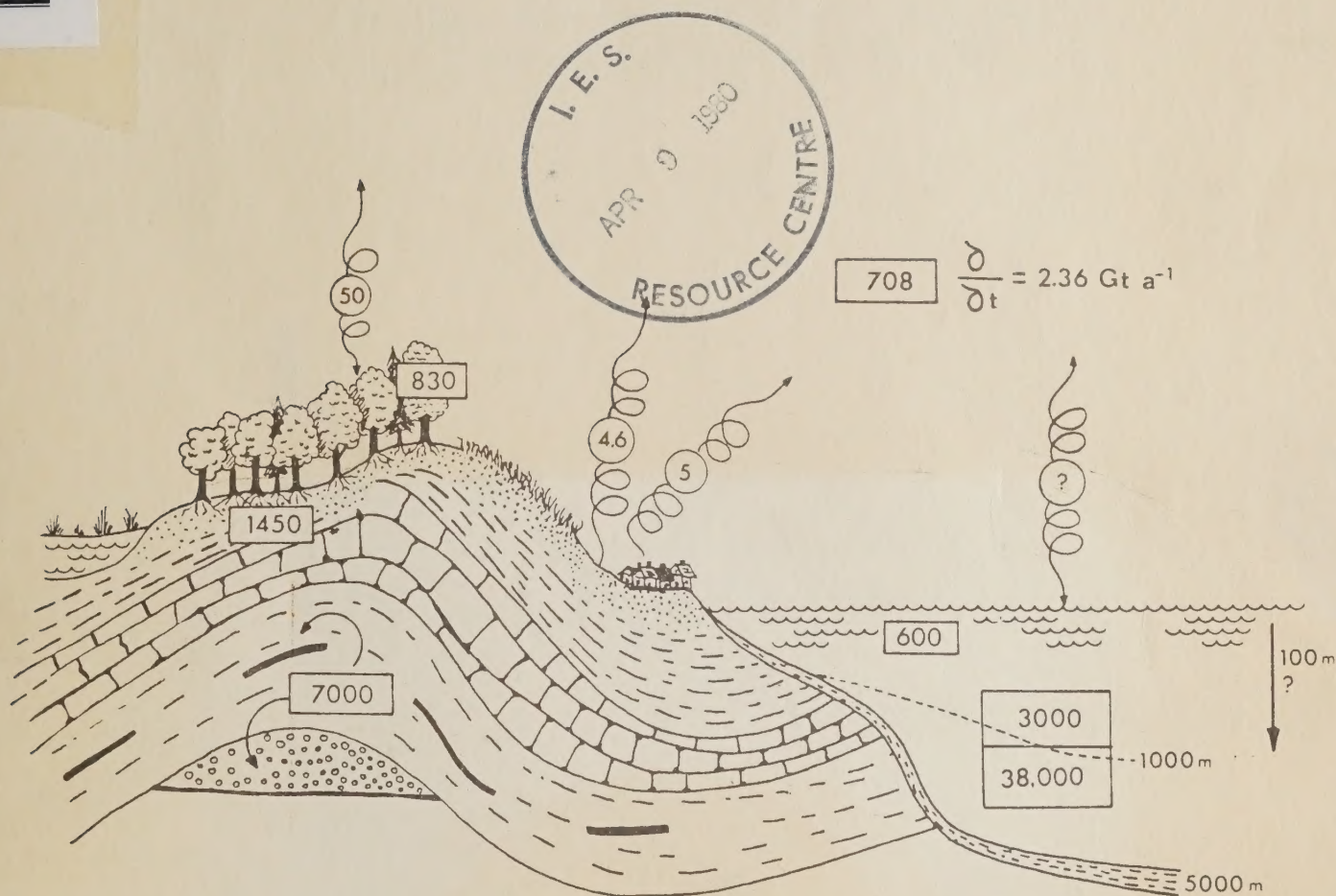
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CARBON DIOXIDE, ISSUES AND IMPACTS, 1979.

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CARBON DIOXIDE ISSUES AND IMPACTS



INST. FOR ENVIRONMENTAL STUDIES
UNIVERSITY OF TORONTO



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CLIMATE PLANNING BOARD
CANADIAN CLIMATE PROGRAM

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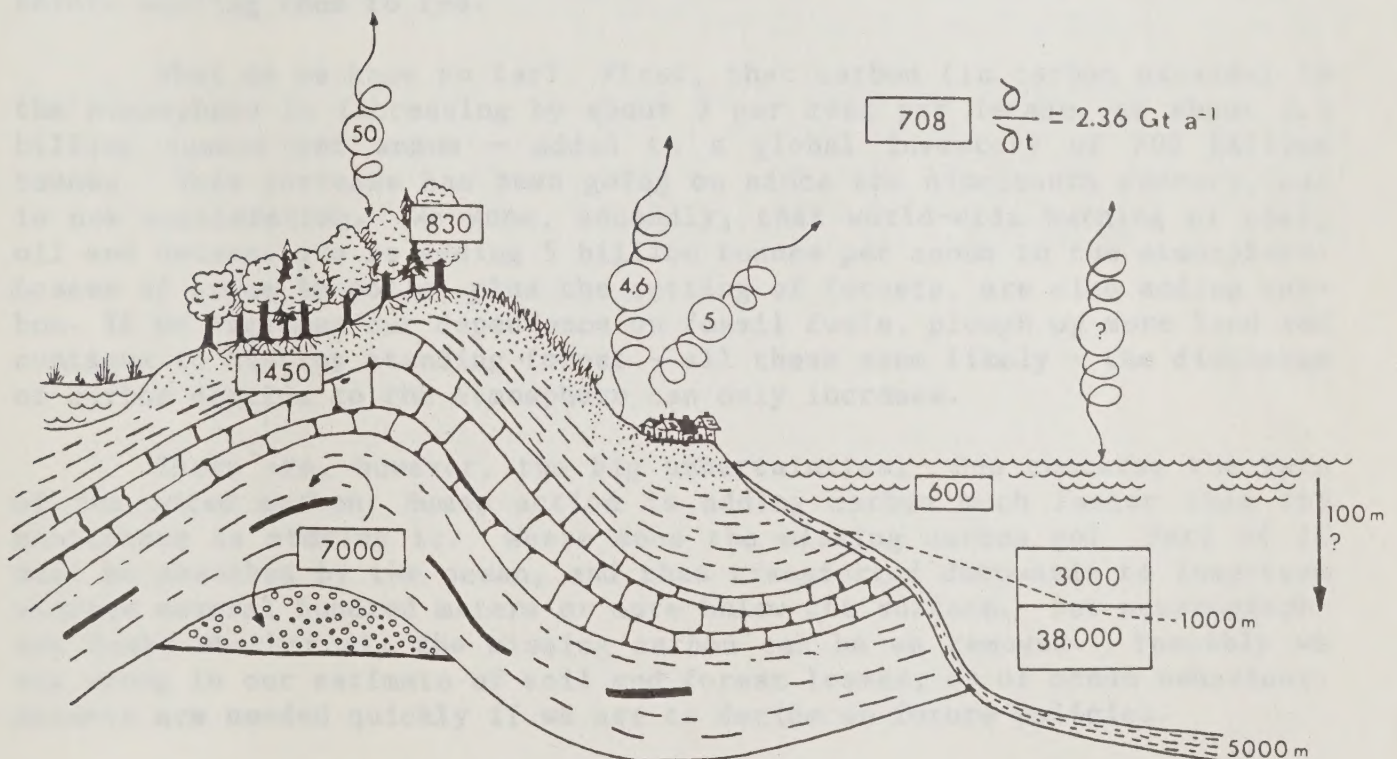
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CARBON DIOXIDE ISSUES AND IMPACTS

Proceedings of the Workshop on
"Energy/Carbon Dioxide Issues and Impacts"
Toronto — August 28-29, 1979



CLIMATE PLANNING BOARD
CANADIAN CLIMATE PROGRAM

CARBON DIOXIDE
ISSUES AND IMPACTS

POLICY IMPLICATIONS

Summary statement by the Chairman of the Climate Planning Board

The steady world-wide build-up of carbon dioxide in the atmosphere is causing widespread concern, since it may have drastic effects on future climate - and hence on the human economy. Energy, forests and farm policies must take account of the possible consequences.

In energy policy, as F.W. Belaire puts it in the report, "we know enough now... to declare a 'condition of caution' with reference to incremental reliance on fossil fuels", because the burning of such fuels is the largest known source for the increase in carbon dioxide level. "We will have to know a lot more, however," he continues, "to declare a 'condition of extreme danger - stop!' to determine an end to the fossil fuel age." In the Climate Planning Board's view, Belaire hits the nail on the head. The signals are yellow at present. We need to know more about the carbon cycle before setting them to red.

What do we know so far? First, that carbon (in carbon dioxide) in the atmosphere is increasing by about 3 per cent per decade, or about 2.3 billion tonnes per annum - added to a global inventory of 708 billion tonnes. This increase has been going on since the nineteenth century, but is now accelerating. We know, secondly, that world-wide burning of coal, oil and natural gas is adding 5 billion tonnes per annum to the atmosphere. Losses of humus in soils, plus the cutting of forests, are also adding carbon. If we increase our dependence on fossil fuels, plough up more land and continue to destroy standing forest - all these seem likely - the discharge of carbon dioxide to the atmosphere can only increase.

There are, however, two big uncertainties. One concerns the fate of the added carbon. Human action is adding carbon much faster than the atmosphere is storing it. Where does the missing carbon go? Part of it must be absorbed by the ocean, and then transferred downwards to long-term storage several hundred meters or more below the surface. But oceanographers doubt whether all the missing carbon can be so removed. Possibly we are wrong in our estimate of soil and forest losses, or of ocean behaviour. Answers are needed quickly if we are to decide on future policies.

The other uncertainty is about the effect of carbon dioxide build-up on climate. Atmospheric scientists are unanimous that a doubling of carbon dioxide levels - likely early in the next century, if fossil fuel consumption continues to increase - will raise world surface temperatures, perhaps by 2 degrees Celsius. The effect will be much larger in high latitudes. Canada will get appreciably warmer, and this alone will call for big adjustments in agriculture, forestry and fisheries. What we cannot yet predict (because our models are not good enough) is the likely effect on rain and snow. Probably it would be profound. Some regions will get much wetter, others much drier. The continental interiors - like our own Prairies - will certainly be affected. But we cannot yet say who will win or who will lose, either within Canada, or as between nations.

We are reasonably sure, however, that the carbon dioxide build-up will continue. The energy use scenarios presented at the Workshop, if correct, allow no other interpretations. At present it looks as if such a continued build-up must have a drastic effect on world climate, even though we cannot predict the details. That is why we think the country should be on yellow alert.

The alert should be in effect in at least three areas. One is energy policy. A wholesale expansion of fossil fuel consumption world-wide may turn out to be unacceptable. Another is forest policy. It may be necessary to work toward world-wide stabilization of carbon storage in living trees. And the third is farm policy. The loss of soil carbon that has been so rapid in the past century is bad for crops and bad for the farmer. It may also be very bad for climate.

The alert should also be heeded in the setting of social and economic policies that relate to the long-term. Planning such as for regional development and major capital investments should be attuned to the possible consequences of induced climate change. Finally, monitoring of climate change must be implemented to develop understanding and to know when the signal is changing from yellow to red.

This Workshop addressed these questions. The Climate Planning Board recognizes that definitive answers to the questions demand a long-term research and monitoring program. Energy policy alone demands the best answers possible within the next five years. Both the magnitude and the urgency of the challenge are quite clear.

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Climate Planning Board*

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*September 1979

The Canadian Climate Program

The Canadian Climate Program is a response to the growing dependence of society on the need to adapt to and optimize the use of its climate resources. Society's increasing vulnerability to climate is a matter of growing concern, that is heightened by the additional uncertainty of how mankind too, might be changing the climate. The answer to the climate problem is the prudent use of climate resources, and it involves our whole society, not just the climatologist.

The Program attempts to:

- 1) integrate and provide a focus for Canadian activities related to climate,
- 2) promote and provide the climate information service that is in the best interests of Canadians,
- 3) improve understanding of the climate system as needed for the provision of inputs to decision-making,
- 4) develop a capability to predict climate on a monthly, seasonal, annual and longer basis, and to predict the effect of mankind on climate,
- 5) improve understanding of and the ability to predict the consequences of climatic change and variations on human activities, the economy and the environment.

The Program has evolved from a conceptual stage in 1974 to the present active "design and development" stage in which an attempt is being made to identify the many Program elements. This is being done by reviewing existing programs defining needs, and the developing strategies to respond to these needs.

The Program strategy and policy are set by the Climate Planning Board whose members are identified above. The Board is advised by a Climate Advisory Committee which provides a voice for those who have a major interest in the Program. The executive arm of these two committees is the Canadian Climate Centre which provides a secretariat and is accountable for certain national climate programs within its own organization.

Within the design phase, consideration is being given to the programs and structures needed to serve regional, provincial, university, industrial and other sectoral needs.

Preface

The role of the World Climate Programme and National Climate Programs is to aid society in coping with climatic problems and exploiting climatic opportunities. The role of the Canadian Climate Program is to reduce the uncertainty surrounding such problems, and to make readily available the best science and information possible in responding to the myriad of climate-related decisions that confront all Canadians.

In the developing Canadian Climate Program, consideration is being given to the possibility that present and planned activities may significantly effect our climate over the long run. Of greatest concern in this area is the question of the climatic consequences of increased levels of atmospheric carbon dioxide, which may be important in the determination of energy policy over the next several decades. For this reason the first workshop in the series was on Carbon Dioxide, Energy and Climate Change. Another consideration is the ability of society to cope with and take advantage of the natural variability in climate. This characteristic will be the main topic for consideration in subsequent workshops on Agriculture, Energy, Renewable Resources, Fisheries, Industry and Construction. Still other workshops will be held which will consider scientific knowledge and methods that are needed to respond to these considerations. By this process the Climate Planning Board hopes to design the Climate Program that is most relevant to Canadian needs and responsibilities abroad.

Introduction

Speculation on the "greenhouse effect" of increasing atmospheric carbon dioxide has attracted generations of scientists. This speculation has now turned to concern as atmospheric measurements and models give substance to theories. "Limits-to-growth" thinking has led to the realization that the consequences of increasing atmospheric carbon dioxide must be considered in deciding the world's energy mix over the next few centuries. Present levels are about 15 percent higher than they were late in the last century, and physical reasoning indicates the process will accelerate over the foreseeable future. The consequences can be estimated, but only in a very generalized, scenario form, and on the assumption that other processes that control climatic-change are known and predictable. This is not the case at present. The problem is particularly challenging to polar latitude countries since reasoning suggests these will be most affected. It is vital that Canada be well informed on and in a position to act upstream of problems that may arise from induced climatic change.

This report is an initial inventory of Canadian activities and capabilities relative to the carbon dioxide question as well as of Canadian perceptions of the issue and responses to it. It presents primarily the findings of four working groups that considered: 1) future energy scenarios, 2) the carbon dioxide balance, 3) climate models and, 4) the impacts of CO₂ on society and the environment. The working group reports are preceded in the text by theme papers prepared by working group chairmen as a basis for discussion of the general concerns and the state of our knowledge. The report lists Canadians involved in CO₂ oriented-activities and their projects (Annex I); this annex is not exhaustive, and clearly many of the persons listed do not consider themselves experts with respect to carbon dioxide; however, they are all well informed, motivated or otherwise interested in the carbon dioxide question. A description of the United States Department of Energy Carbon Dioxide Effects Research and Assessment Program is presented as Annex 2.

LIST OF RECOMMENDATIONS

Carbon Dioxide Balance Working Group

1. A comprehensive analysis of the carbon cycle within Canadian land, sea and air should be a central part of the Canadian Climate Program.
2. An effective coordinating mechanism -- presumably an interdisciplinary, interagency committee -- will be needed to coordinate Canadian research on the carbon cycle to ensure the free flow of information between groups involved.
3. All work on the carbon cycle in Canada should relate as closely as possible to international programs planned or in progress. Close liaison should also be maintained with national programs in suitable countries, such as the U.S., the Scandinavian countries, Finland and the Soviet Union.
4. The present program of monitoring carbon dioxide concentration at Alert, Sable Island and Ocean Weather Ship Papa should be maintained.
5. All monitoring of gaseous and liquid-phase carbon dioxide levels and transfers requires scrupulous attention to calibration and reference to international laboratory standards. These standards should be maintained.
6. The Canadian Biomass Program should be modified so as to provide direct information concerning the stored carbon and rates of natural fixation for as many sites and environmental conditions as possible.
7. Estimates should also be made of the volume, carbon content and oxidation/growth states of Canadian peat deposits (including rates of post-glacial accumulation).
8. The special role of fire in accelerating the transfer of biotic and soil carbon to the atmosphere should be examined in depth.
9. Canada should acquire sufficient capabilities in isotope methods needed for CO₂ research. The ¹³C/¹²C ratio and ¹⁴C content in tree rings and other organic materials offer valuable insights into the rates of carbon accumulation and release. Oxygen-isotope methods also have much to contribute, especially in the analysis of marine sediments.
10. Encouragement should be given to attempts to develop models of the overall carbon cycle, and to render such models compatible with the ocean-atmosphere models now being developed.
11. Estimates should be made as soon as possible of the storage and annual rate of exchange of carbon in Canadian soils, with major emphasis on agricultural soils, especially as to the effects of farm practice on carbon levels; litter and soil storage in the major forest formations; and the carbon content and rates of recovery of burned-over and cut-over forest soils (see Recommendation 8 above).

12. Efforts should be made towards a better understanding of ocean mixing processes, and of other modes of downward transfer of carbon from the surface waters of the ocean. The mechanisms of downwelling and mixing to moderate and bottom depths require much attention.

13. Attention should be given to the further use of geochemical tracers and isotope methods in such research, particularly as regards oceanic tritium and helium. The Pacific and Arctic waters should be investigated using such techniques.

Energy Scenario Working Group

1. In striving for viable energy balances, Canada should choose energy systems which can cope with as yet ill defined but possibly serious, global and regional consequences of significantly higher concentrations of CO₂ in the atmosphere.

2. All levels of government, but particularly provincial governments in their regulatory capacity, the universities and private sectors should be involved in related research and policy planning directed to the above objectives.

3. Priority in research should be given to (i) reducing the uncertainty in the related socioeconomic and physical chemical processes, and (ii) enhancing our capacity to cope with uncertainty by developing more resilient systems, more specifically the following four types of action should be undertaken in both a national and global context:

Canada's Particular Interest

Canada in a Global Context

Dealing with uncertainty

- agricultural research to develop crops viable under different climatic regimes
- alternative energy sources, and systems
- fusion, biomass etc.
- promoting energy conservation, more efficient energy use
- research to prepare to cope with changes in water availability as a result of climate change, droughts or floods

Reducing uncertainty

- monitoring Canadian energy use (joining federal-provincial activity) to predict CO₂ production
- climate research
- monitoring, looking for man-induced changes

Climate Models Working Group

1. Strong support is required for climate modelling. In particular a substantial increase in computer resources is required in order to exploit the existing Canadian climate model to provide quantitative estimates of global and regional climatic changes resulting from projected CO₂ increases. Computers up to the task are available and presently in use for these purposes in the U.S.A. and Europe.
2. Research support to universities and oceanographic centres in Canada must be increased to promote new activities in modelling of physical processes. High priority should be given to the study of cloud and ocean parameterization as related to climate modelling.
3. Diagnostic studies of the trends and budgets of the components of the climate system need to be strongly encouraged. In particular new activities are required in the area of large-scale ocean budgets and the cryosphere in northern latitudes. Such studies will necessarily involve international collaboration in the context of the World Climate Research Program.
4. Existing observational programs in the Canadian arctic and middle north must be maintained at a level which ensures the long-term monitoring of the climate in this crucial area. Further, Canada should play a role in the implementation of future global monitoring systems by active international collaboration in both the design and development of satellite observing systems and the subsequent data reduction and analysis.
5. A re-examination of the Canadian system of data analysis and archiving should be undertaken to ensure that the requirements for climate research are met both in a national and international context. Of particular concern is the development of physically consistent data sets from existing archives.

Socioeconomic Impacts Working Group

1. A program to increase public awareness and discussion is needed.
2. Expertise available to the Canadian Climate Centre should be expanded to include geographers, sociologists and economists.
3. A national advisory committee on impact analysis should be created.
4. The Canadian Climate Program should develop a framework for establishing priorities for research and development directed to the assessment of climatic change and its impacts, primarily in relation to potential effects on Canadian society.

5. Using the above-mentioned framework, resource requirements need to be established and decisions made regarding their distribution, e.g. in-house, grants, contracts.
6. Better interaction is needed between those scientists concerned with climatic processes and impact analysts in order to establish the needs of the latter group for climatic inputs to socioeconomic analysis.
7. In view of the international nature of the CO₂ question, close liaison with concerned agencies in other countries and with international agencies such as the United Nations Environmental Programme, the International Council of Scientific Unions is needed.

CANADIAN DIORITE BALANCE OF P.K. BALANCE

By "Carbon dioxide balance" it is meant that the composition of the atmosphere must have had in mind the aspects of the complete carbon cycle that must exist in any atmosphere. The composition of the atmosphere is not a static thing, but a dynamic one, and it is the balance of the carbon cycle that is of interest. I think, therefore, that it is better to call the whole cycle, even though we may not have a complete picture of it, the "carbon cycle" and not the "carbon dioxide balance".

Why Is the Carbon Cycle Important?

The atmosphere currently contains 11 parts per million by volume of carbon dioxide, corresponding to 0.00011% of the weight of the atmosphere (see figure 1).

During the last 100 years, the amount of carbon dioxide in the atmosphere has increased by about 10%. This is a very small increase, but it is a very important one. It is the only increase of any kind that has been observed in the atmosphere. The increase is due to the burning of fossil fuels, which is the only source of carbon in the atmosphere. The increase is also due to the fact that the atmosphere is not a static thing, but a dynamic one, and it is the balance of the carbon cycle that is of interest. I think, therefore, that it is better to call the whole cycle, even though we may not have a complete picture of it, the "carbon cycle" and not the "carbon dioxide balance".

THEME PAPERS

- (1) The carbon cycle is a dynamic system, and it is the balance of the carbon cycle that is of interest. I think, therefore, that it is better to call the whole cycle, even though we may not have a complete picture of it, the "carbon cycle" and not the "carbon dioxide balance".
- (2) The carbon cycle is a dynamic system, and it is the balance of the carbon cycle that is of interest. I think, therefore, that it is better to call the whole cycle, even though we may not have a complete picture of it, the "carbon cycle" and not the "carbon dioxide balance".

Production of carbon dioxide is a dynamic process, and it is the balance of the carbon cycle that is of interest. I think, therefore, that it is better to call the whole cycle, even though we may not have a complete picture of it, the "carbon cycle" and not the "carbon dioxide balance".

The main transfer mechanism for carbon is the carbon cycle, and it is the balance of the carbon cycle that is of interest. I think, therefore, that it is better to call the whole cycle, even though we may not have a complete picture of it, the "carbon cycle" and not the "carbon dioxide balance".

- (1) The carbon cycle is a dynamic system, and it is the balance of the carbon cycle that is of interest. I think, therefore, that it is better to call the whole cycle, even though we may not have a complete picture of it, the "carbon cycle" and not the "carbon dioxide balance".

CARBON DIOXIDE BALANCE

BY

F.K. HARE

By "carbon dioxide balance", I think that the organizers of the Workshop must have had in mind those aspects of the complete carbon cycle that touch most closely on atmospheric carbon dioxide content, and hence on world climate. Carbon cycles not only between physical reservoirs like the atmosphere, biota, soils and oceans, but between different chemical species. I think, therefore, that we shall be talking about the whole cycle, even though we lay most stress on exchanges with the atmosphere. And specifically, we shall focus on Canada's place in these exchanges, and our interest in their performance.

Why Is the Carbon Cycle Important?

The atmosphere currently contains 335 parts per million by volume of carbon dioxide, corresponding to 708 gigatonnes ($\text{Gt} = 10^9$ tonnes) of carbon (see figure 1).

Burning of coal, oil, natural gas and wood by man is adding about 5 Gt of carbon per annum ($\text{Gt a}^{-1}\text{C}$) to this total. Monitoring shows, however, that the atmospheric load increases by only $2.3 \text{ Gt a}^{-1}\text{C}$. Hence $2.7 \text{ Gt a}^{-1}\text{C}$ must be leaving the atmosphere to enter other stores. It has usually been assumed that most of this is passing into the oceanic reservoir, which is huge. The rest was assumed to be picked up by increasing forest or grassland storage, either in the form of faster plant growth, or as increased carbon content in the soil. These assumptions have been upset in two ways: -

- (i) some oceanographers doubt whether the oceans are capable of storing as much as $2.7 \text{ Gt a}^{-1}\text{C}$, or even half this amount; and
- (ii) biologists and soil scientists have reported that the biota and soils may actually be transferring carbon to the atmosphere, rather than serving as sinks. Some estimates make both biota and soil sources as big as the fossil fuel source.

Prediction of future atmospheric carbon dioxide concentrations requires that these uncertainties be removed. Present technical opinion favours, by a majority, the view that rising carbon dioxide concentrations in the atmosphere are due mainly to fossil fuel consumption. Analysis of the various carbon isotopes in tree rings and other evidence supports this view. But it is important to reconcile the conflicts of evidence and opinion.

The main transfer processes for carbon that we can identify are as follows: -

- (i) Exchange with land biota, due to photosynthesis and respiration, and burning. Carbon stored in the biota probably amounts to about 830 Gt of C. Some recent estimates suggest that the destruction and burning

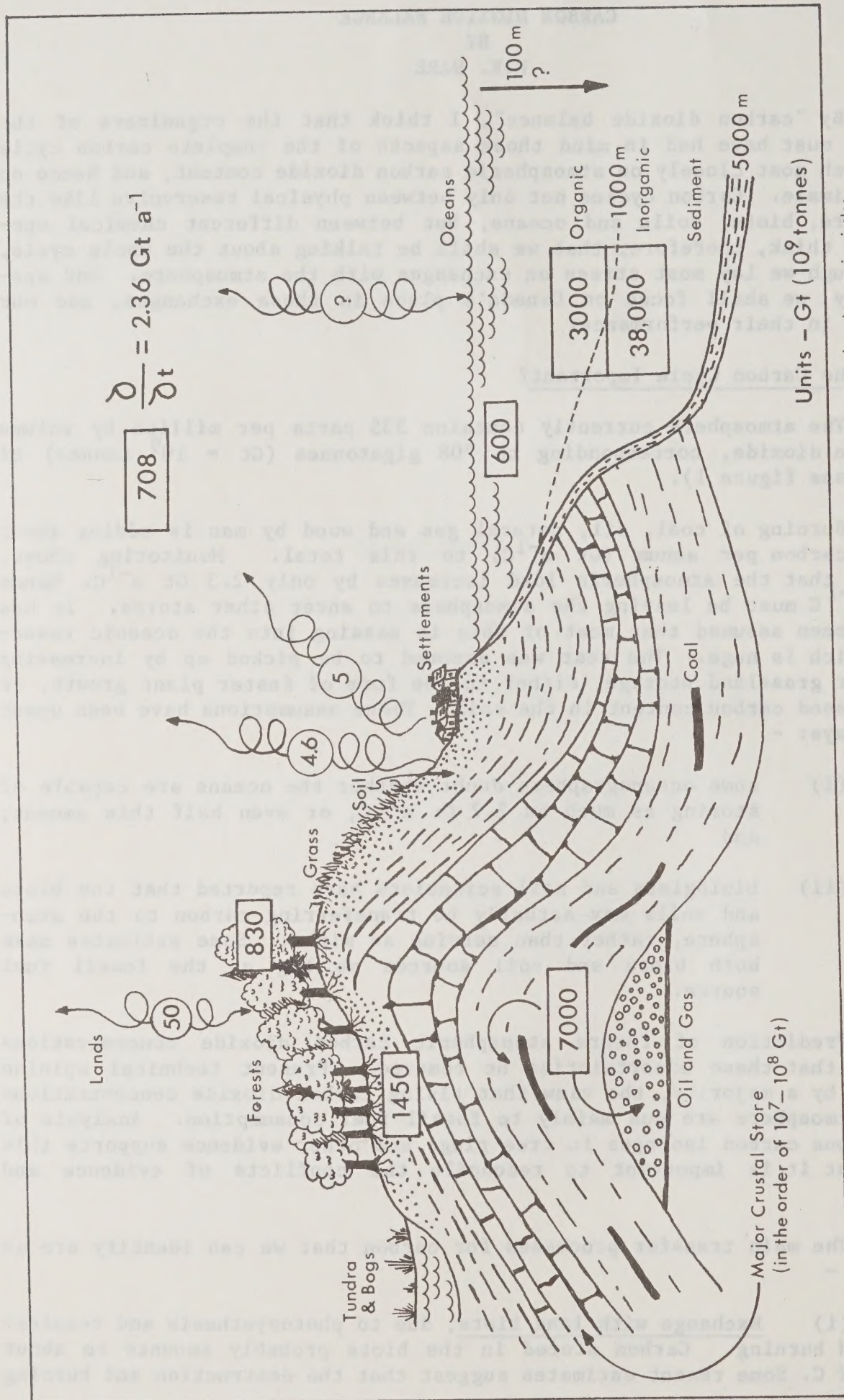


Figure 1 Sketch of the principal reservoirs and exchange routes for the carbon cycle. Storages in rectangular boxes; annual exchanges in circles.

of forests (where most of the carbon is stored) outweighs the effects of afforestation and enhanced tree growth. If so, there must be a net transfer to the atmosphere of an unknown amount; estimates vary from negligible values to figures in the range 2 to 8 Gt $a^{-1}C$ transferred to the atmosphere from land biota. The only Canadian estimate, due to C.S. Wong (1978), is a little above 1.5 Gt $a^{-1}C$ to the atmosphere, chiefly from tropical forest clearance, with subsequent burning of the debris.

(ii) Exchange with soils and peat, due to (a) synthesis of new peat and soil humus, balanced by (b) oxidation of peat, humus and surface litter due to cropping and pasturing land, and drainage of bogs. The reservoir is uncertain, but a new, thorough appraisal by Buringh (1979) gives present storage as 1,447 Gt of C, or twice the amount stored in the biota. The same author gives the annual transfer to the atmosphere as 4.6 Gt $a^{-1}C$, which is much higher than has been previously assumed, and is almost as large as fossil fuel consumption.

(iii) Exchange with oceans, due to solution of atmospheric CO_2 in the surface waters, or release to the atmosphere. The surface waters of the ocean (to a depth of 100 m) store nearly 600 Gt of C, nearly all of it in the form of carbonate, bicarbonate and dissolved CO_2 . This layer exchanges C with the atmosphere at a rate equivalent to an atmospheric residence time of 5 to 10 years. Carbon is transferred downwards into intermediate or deep layers, which exchange with the layers above only very slowly. The intermediate waters of the oceans are the only known major net sink for atmospheric carbon. The oceans down to 1000 m must have served as such a sink for many decades, but there is controversy as to the size of the sink. Revelle and Munk (1977) estimate that only about 45 Gt of C have entered ocean storage, about a fifth of what the atmosphere may have received from other reservoirs.

(iv) Transfer of fossil fuel carbon to atmosphere, due to human industry. The annual rate, chiefly due to the burning of coal, oil and natural gas, is about 5 Gt $a^{-1}C$. This is about one-tenth of the release to the atmosphere from heterotrophic respiration, which is, however, balanced by almost equivalent photosynthesis.

It is apparent that these transfers do not balance. We have estimates of the transfer to the atmosphere as follows: -

From the land biota (Woodwell, 1978) . . .	+2	to +8	Gt $a^{-1}C$
From soils (Buringh, 1979)		+4.6	Gt $a^{-1}C$
From fossil fuels (from statistics) . . .		+5	Gt $a^{-1}C$
Total		11.6 to 17.6	Gt $a^{-1}C$

Total requiring non-atmospheric storage: 9.3 to 15.3 Gt $a^{-1}C$

The only known sink, the intermediate waters of the oceans, are believed by Revelle and Munk to be capable of removing only about 1.5 Gt $a^{-1}C$. Even the higher estimates are usually below 3 Gt $a^{-1}C$. Yet the atmospheric burden is increasing only by 2.3 Gt $a^{-1}C$. Clearly one or all of the above estimates is wrong. In nature, the carbon cycle is closed, and must balance. It does not do so in our models.

The big unknowns include (i) the true size of the biotic and soil reservoirs; (ii) the rates of exchange with these reservoirs; and (iii) the magnitude of the oceanic sink, and the mechanics of exchange between surface and deep waters. All three of these are problems on which Canadian research may have an important bearing.

(ii) Exchange with soils and peat, due to (a) weathering of silicate and other minerals, balanced by (b) oxidation of peat, humus and organic litter due to cropping and pasturing, leads to a release of CO₂. The rate is uncertain, but a rough estimate by Borchert (1973) gives a value of 1.5 Gt C yr⁻¹. The amount of C in the soil is estimated to be 1.5 Gt C. The same author gives the annual transfer to the atmosphere as 0.5 Gt C yr⁻¹, which is much higher than has been previously assumed, and is almost as large as fossil fuel consumption.

(iii) Exchange with oceans. Due to solution of atmospheric CO₂ in the surface waters, or release to the atmosphere. The surface waters of the ocean (to a depth of 100 m) store nearly 600 Gt of C, nearly all of it in the form of carbonate, bicarbonate and dissolved CO₂. This layer exchanges C with the atmosphere at a rate equivalent to an atmospheric residence time of 1 to 10 years. Carbon is transferred downwards into sediments or deep layers, which exchange with the layers above only very slowly. The intermediate waters of the ocean, the only known major sink for atmospheric CO₂, the bottom down to 1000 m, have received as much as 100 Gt of C since 1850, but it is controversial as to the rate at which this has occurred (Revelle and Suess (1957) estimate that only about 25 Gt of C have entered ocean storage, about a fifth of what the atmosphere may have received from other reservoirs).

(iv) Transfer of fossil fuels, either to atmosphere, or to human industry. The annual rate, chiefly due to the burning of coal, oil and natural gas, is about 5 Gt C yr⁻¹. This is about one-tenth of the release to the atmosphere from photosynthesis, which is, however, balanced by almost equivalent photosynthesis.

It is apparent that these estimates are not balanced. We have estimates of the transfer to the atmosphere as follows:

From the land (Borchert, 1973)	1.5 Gt C yr ⁻¹
From soils (Borchert, 1973)	0.5 Gt C yr ⁻¹
From fossil fuels (Borchert, 1973)	5.0 Gt C yr ⁻¹
Total	7.0 Gt C yr ⁻¹
Total potential non-atmospheric storage	9.5 Gt C yr ⁻¹

The only known sink, the intermediate waters of the ocean, are balanced by Revelle and Suess to be capable of removing only about 1.5 Gt C yr⁻¹. Even the higher estimates are usually below 2 Gt C yr⁻¹. Clearly one or all of the sources is increasing only at 2.5 Gt C yr⁻¹. Clearly one or all of the above estimates is wrong. It is evident, the carbon cycle is closed, and must balance. It does not do so in our models.

ENERGY SCENARIO

BY

F.W. BELAIRE

Climate is such an all pervasive conditioning factor in our lives that we tend to ignore it as an explicit factor in our decision-making processes. This Workshop has already forced me to think of climate as a positive and objective element in decision-making. The emerging awareness of the role of climate, the requirement to monitor man's impact on it, and the need to anticipate and adapt to climate change all call for a perceptual shift.

Climate has taken on many of the characteristics of a natural resource with the requisite responsibility of resource management. This Workshop has the task of exploring the interface between energy and climate. How do we take climate, or climate changes, into account in striving to achieve viable world and regional energy balances? The world's need for more energy will be driven by the growth and distribution of the world's population and the extent to which the economic aspirations of these people can be realized.

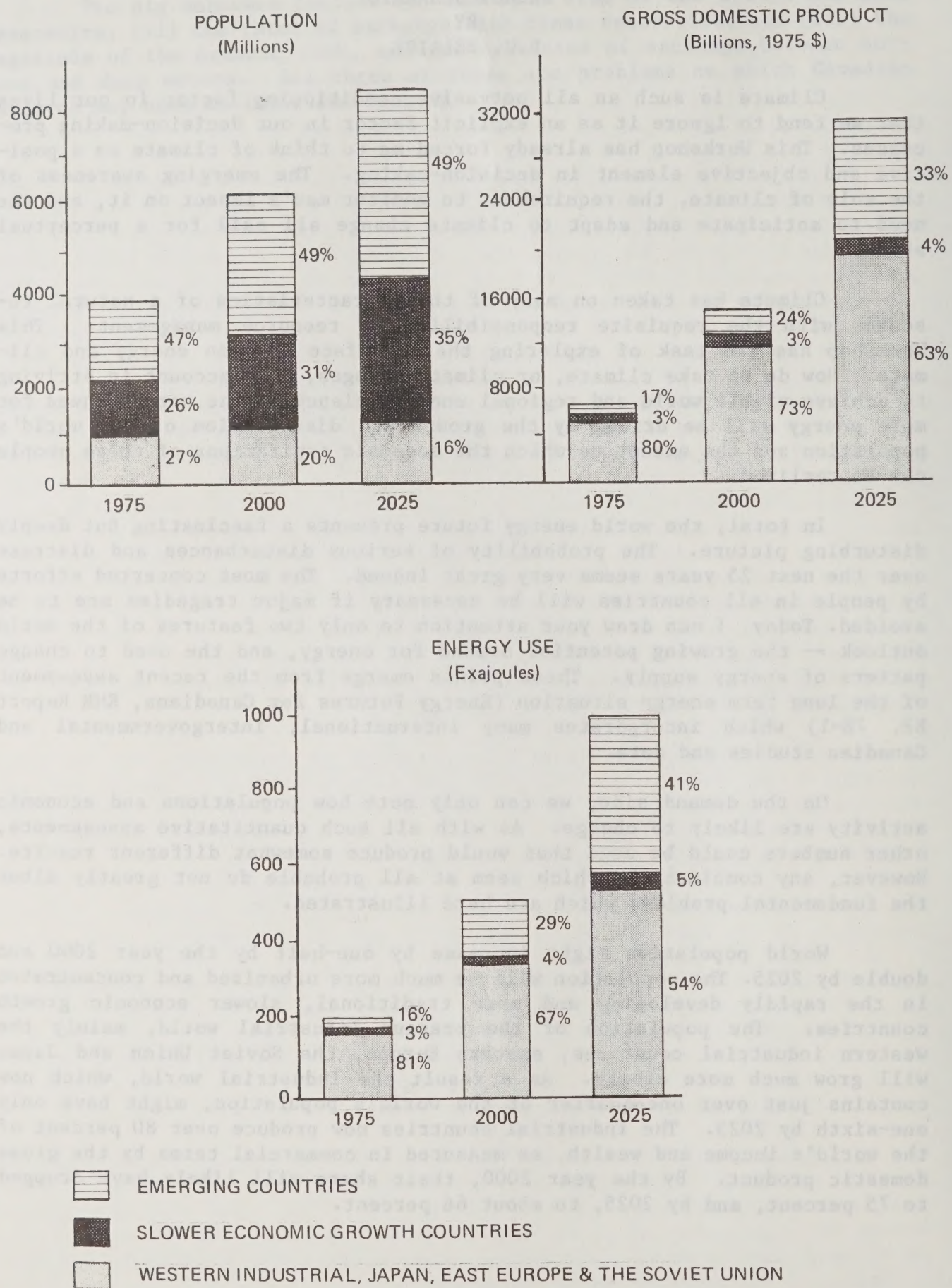
In total, the world energy future presents a fascinating but deeply disturbing picture. The probability of serious disturbances and distress over the next 25 years seems very great indeed. The most concerted efforts by people in all countries will be necessary if major tragedies are to be avoided. Today, I can draw your attention to only two features of the world outlook -- the growing potential demand for energy, and the need to change patterns of energy supply. These points emerge from the recent assessment of the long term energy situation (Energy Futures for Canadians, EMR Report EP. 78-1) which incorporates many international, intergovernmental and Canadian studies and data.

On the demand side, we can only note how populations and economic activity are likely to change. As with all such quantitative assessments, other numbers could be used that would produce somewhat different results. However, any combinations which seem at all probable do not greatly alter the fundamental problems which are here illustrated.

World population might increase by one-half by the year 2000 and double by 2025. The population will be much more urbanized and concentrated in the rapidly developing and more traditional, slower economic growth countries. The population of the present industrial world, mainly the western industrial countries, eastern Europe, the Soviet Union and Japan will grow much more slowly. As a result the industrial world, which now contains just over one-quarter of the world's population, might have only one-sixth by 2025. The industrial countries now produce over 80 percent of the world's income and wealth, as measured in commercial terms by the gross domestic product. By the year 2000, their share will likely have dropped to 75 percent, and by 2025, to about 66 percent.

Figure 2

WORLD POPULATION, GROSS DOMESTIC PRODUCT AND ENERGY USE



In other words, certain other countries will be expanding their economic activity much more rapidly than the presently industrialized countries and, consequently, placing much greater demands on world energy.

The share of the developing countries in world energy demand would increase from less than 20 percent today to more than 30 percent by the year 2000, and to nearly 50 percent in 25 years beyond that. Even by the year 2000, the potential additional energy demand from the developing countries might be almost as great as the total demand by the industrial countries today. As the existing industrial countries tighten their energy belts, the resulting moderation in demand could be more than offset by the burgeoning demand of the new industrial world.

Even the traditional stagnant economies of the countries of the Indian sub-continent and Africa, south of the Sahara, will place important new demands on world energy as their rapidly growing populations already exceed the carrying capacity of their traditional non-commercial forms of energy. This raises the sobering fact that these populous societies, despite their limited ability to pay or to influence the market, are now for the first time and henceforth dependent on commercial energy. An additional serious fact is that the economies, and thus the energy needs, of a large number of the traditional, stagnant societies are very vulnerable to small climate variations, which alter the fertility of sub-arid lands, change the pattern of monsoons, or the flood regime of major rivers.

Those trends in population, wealth and energy highlight one critical consideration -- the future role of oil in world economies and societies. Oil now provides almost one-half of all the commercial, primary energy used in the world. There is no apparent way for it to provide anything like one-half even in 20 years' time.

Figure 3 WORLD SUPPLY AND RESERVES OF CONVENTIONAL OIL 1977-2025

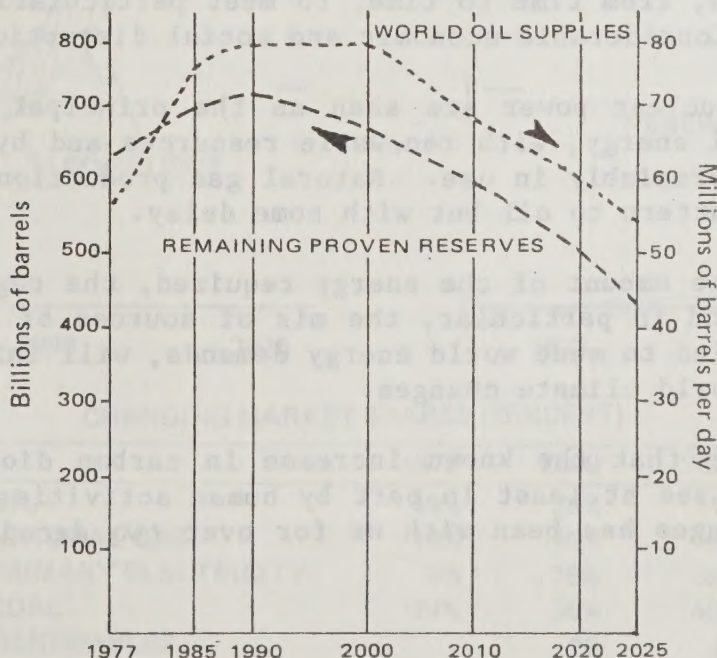


Figure 3 illustrates the peaking and decline of world conventional oil production and remaining proven reserves. It can be seen from the figure that world oil production might reach its maximum at about 80 million barrels a day in the early 1990s, increasing from the nearly 60 million barrels a day now produced. Beyond the early 1990s, oil production declines until, perhaps by 2010, world oil production is back to about current levels of production even though the world's energy preferences would be to use much greater quantities of oil. The increases in world energy demand and the peaking and subsequent decline in world oil production pose a very threatening problem.

Thus, major adjustments in world energy systems away from such heavy reliance on oil must be made prior to the year 2000. Those adjustments will then continue beyond 2000. A reasonable estimate of the possible substitution of electricity and coal (and some additional renewables) for oil and natural gas is shown in Figure 4.

The lower share of oil which is shown in figure 4 for the years 2000 and 2025 is a forced reduction in the use of oil, not a preferred solution. It is made necessary by the sheer inability to produce all of the oil that people would use if it were available. There is no reason to expect that a forced wrenching away from dependence on oil will occur automatically, willingly, or smoothly. Such a change in energy use contains a potential for massive disruptions on a world scale. A lower rate of energy use growth might occur, but a severe reduction also would bring with it economic and social distress.

The pressures of increasing world demand on limited oil production are expected to be evident well before the year 2000, and to result in substantial further increases in oil prices -- at least doubling in real terms (beyond the rate of increase in prices generally) before 2000. However, it appears unlikely that these price signals will be received soon enough to lead to an early start on the necessary, large-scale adjustments which would be required for orderly transition. Such adjustments to a more sustainable energy supply use system should already be underway but they are not. Even more disturbing might be serious interruptions in supply, or inabilities, from time to time, to meet particularly heaving pressures of demand. Considerable economic and social disruption could result.

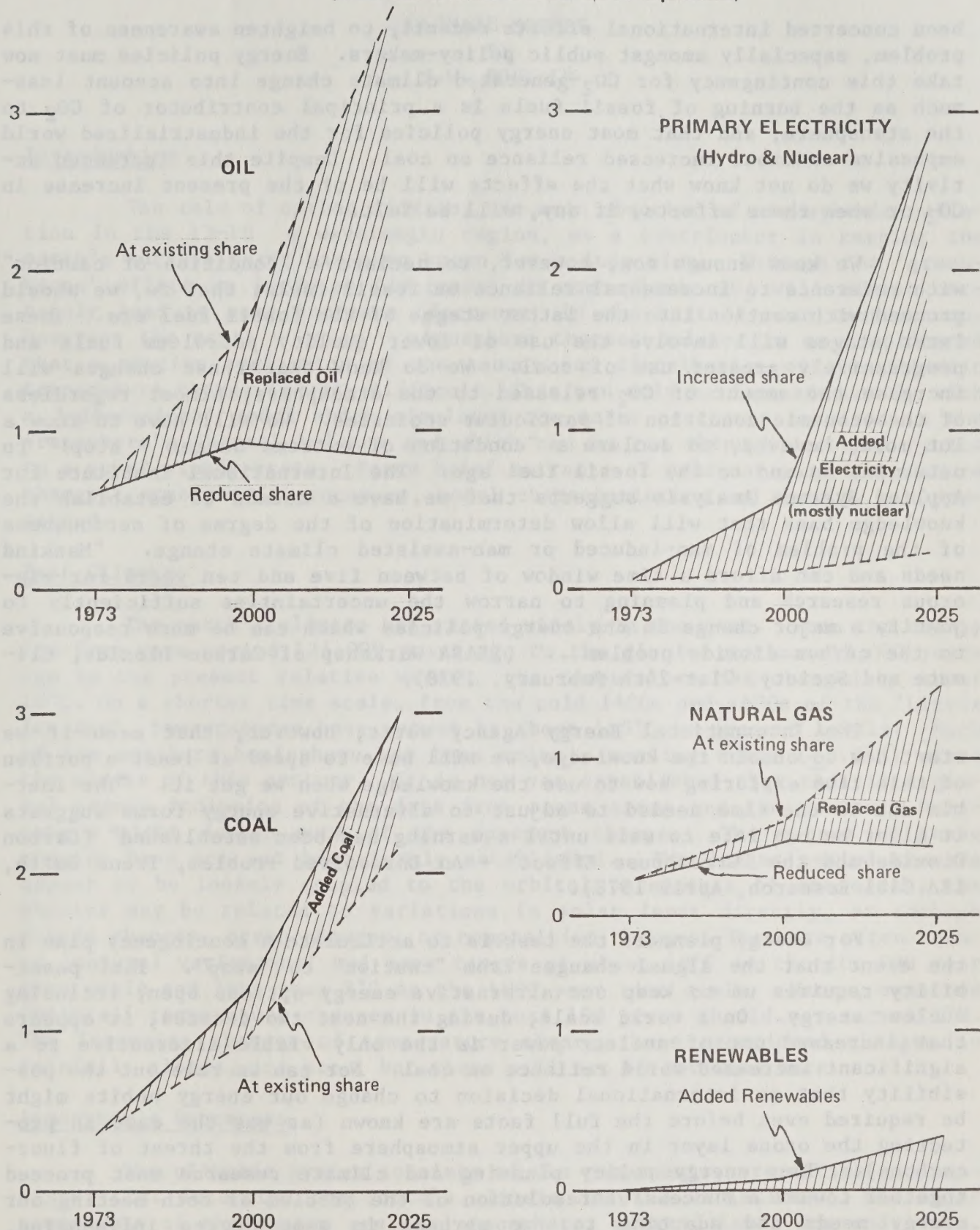
Coal and nuclear power are seen as the principal sources of the required additional energy, with renewable resources and by-product energy also increasing appreciably in use. Natural gas production is expected to follow a similar pattern to oil but with some delay.

The absolute amount of the energy required, the regional incidence of energy needs, and in particular, the mix of sources of energy that can or will be marshalled to meet world energy demands, will influence and will be influenced by world climate changes.

The concern that the known increase in carbon dioxide content of the atmosphere, caused at least in part by human activities, could lead to global climate changes has been with us for over two decades. There have

Figure 4

WORLD SUBSTITUTION FOR OIL AND NATURAL GAS (Hundreds of Millions of Barrels Oil Equivalent)



CHANGING MARKET SHARES (PERCENT)

	1973	2000	2025
OIL	49%	28%	11%
NATURAL GAS	19%	15%	6%
PRIMARY ELECTRICITY	3%	16%	39%
COAL	29%	38%	40%
RENEWABLES		2%	4%

been concerted international efforts recently to heighten awareness of this problem, especially amongst public policy-makers. Energy policies must now take this contingency for CO₂-generated climate change into account inasmuch as the burning of fossil fuels is a principal contributor of CO₂ to the atmosphere, and that most energy policies for the industrialized world emphasize enormous increased reliance on coal. Despite this increased activity we do not know what the effects will be of the present increase in CO₂ or when these effects, if any, will be felt.

We know enough now, however, to declare a "condition of caution" with reference to incremental reliance on fossil fuels; that is, we should proceed with caution into the latter stages of the fossil fuel era. These later stages will involve the use of lower quality petroleum fuels and progressively greater use of coal. We do know that these changes will increase the amount of CO₂ released to the atmosphere, almost regardless of the economic condition of particular societies. We will have to know a lot more, however, to declare a "condition of extreme danger - stop!" to determine an end to the fossil fuel age. The International Institute for Applied Systems Analysis suggests that we have a decade to establish the knowledge base that will allow determination of the degree of seriousness of the problem of man-induced or man-assisted climate change. "Mankind needs and can afford a time window of between five and ten years for vigorous research and planning to narrow the uncertainties sufficiently to justify a major change in the energy policies which can be more responsive to the carbon dioxide problem..." (IIASA Workshop of Carbon Dioxide, Climate and Society, 21st-24th February, 1978).

The International Energy Agency warns, however, that even if we start now to obtain the knowledge, we will have to spend at least a portion of this time exploring how to use the knowledge when we get it. "The inertia due to the time needed to adjust to alternative energy forms suggests it might be too late to wait until a warning has been established" (Carbon Dioxide and the "Greenhouse Effect" - An Unresolved Problem, Irene Smith, IEA Coal Research, April 1978).

For energy planners the task is to articulate a contingency plan in the event that the signal changes from "caution" to "stop". That possibility requires us to keep our alternative energy options open, including nuclear energy. On a world scale, during the next two decades, it appears that increased use of nuclear power is the only viable alternative to a significant increased world reliance on coal. Nor can we rule out the possibility that an international decision to change our energy habits might be required even before the full facts are known (as was the case in protecting the ozone layer in the upper atmosphere from the threat of fluorocarbons). Thus energy policy planning and climate research must proceed together toward a successful resolution of the problem of both meeting our energy needs and adapting to, or perhaps in some degree influencing, changes in climate.

CLIMATE MODELS

BY

B.W. BOVILLE

Introduction

The role of carbon dioxide, the main absorber of atmospheric radiation in the 13-18 μ wavelength region, as a contributor in keeping the earth's surface warm, has been known for a long time. Through the 'greenhouse' effect an increase (decrease) in atmospheric CO_2 will almost certainly lead to some increase (decrease) in the earth's mean temperature. However, the earth - ocean - atmosphere thermal balance is so complicated that a precise evaluation of the amount and distribution of the climatic temperature change is very difficult. This can only be done adequately with a 3-dimensional model which simulates the major processes involved in the atmosphere's thermal balance and which can be run through seasonal cycles to a quasi steady-state. Hence brief extracts of relevant past temperature changes, atmospheric processes, model characteristics and results are presented.

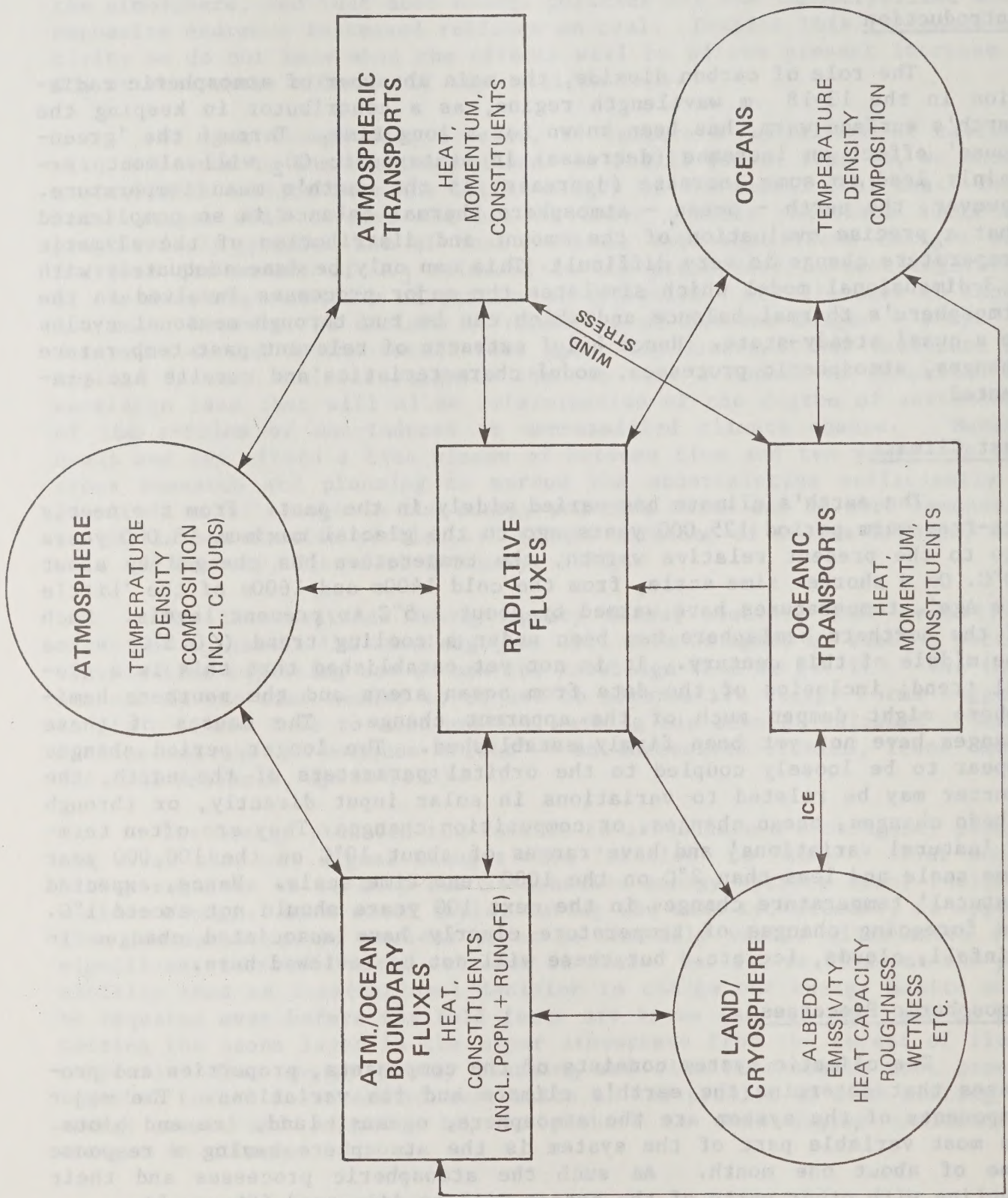
Past Climate

The earth's climate has varied widely in the past. From the nearly ice-free warm period 125,000 years ago to the glacial maximum 18,000 years ago to the present relative warmth, the temperature has changed by about 10°C . On a shorter time scale, from the cold 1400s and 1600s of the 'Little Ice Age', temperatures have warmed by about 1.5°C to present levels. Much of the northern hemisphere has been under a cooling trend ($\leq 0.5^\circ\text{C}$) since the middle of this century. It is not yet established that this is a global trend; inclusion of the data from ocean areas and the southern hemisphere might dampen much of the apparent change. The causes of these changes have not yet been firmly established. The longer period changes appear to be loosely coupled to the orbital parameters of the earth, the shorter may be related to variations in solar input directly, or through albedo changes, ocean changes, or composition changes. They are often termed 'natural variations' and have ranges of about 10°C on the 100,000 year time scale and less than 2°C on the 1000 year time scale. Hence, expected 'natural' temperature changes in the next 100 years should not exceed 1°C . The foregoing changes of temperature clearly have associated changes in rainfall, clouds, ice etc., but these will not be reviewed here.

Atmospheric Processes

The climatic system consists of the components, properties and processes that determine the earth's climate and its variations. The major components of the system are the atmosphere, oceans, land, ice and biota. The most variable part of the system is the atmosphere having a response time of about one month. As such the atmospheric processes and their coupling with other parts of the system will be discussed (Figure 5).

Since the atmosphere is thermodynamically driven, temperature is a fundamental climatic variable whose variations determine most other changes through complex, interactive processes. The basic processes involved are



Sketch of the components, properties and processes of the climate system.

Figure 5

the radiative exchanges. Variations in incident solar radiation give rise to diurnal, seasonal and longer-period changes. The amount of incident solar radiation passing through the atmosphere and available to heat the surface also varies with clouds, albedo, aerosol content and gaseous composition e.g., O_3 . The amount of terrestrial radiation returned through the atmosphere to space depends mainly on the temperature of the emitting surface and the concentrations of the so-called 'greenhouse' constituents (primarily water vapour and CO_2 plus aerosols, clouds and O_3).

The troposphere is largely transparent to solar radiation and is heated from below by convective overturning. Thus the fluxes of heat and water vapour etc. through the water, ice and land (incl. biota) interface determine the state of the lower atmosphere. The small-scale and large-scale convective overturnings in the atmosphere determine where the latent heat is released, where the clouds form and where the rain falls.

Transport and diffusion in the atmosphere act to provide a nearly uniform distribution of CO_2 over the globe. Additional amounts of CO_2 would increase the 'greenhouse effect' and raise temperatures near and at the surface and lower them in the stratosphere and upper atmosphere. If other things were equal, this might be of little importance. However, increasing temperatures melt snow and ice which lower the albedo and enhances the absorption of solar radiation thus further increasing the surface temperature, a positive feed-back mechanism. Higher surface temperatures favour more evaporation into the atmosphere hence, higher water vapour concentrations which also increases infra-red absorption and contributes to higher surface temperatures, another positive feedback. However, increased water vapour concentrations could lead to greater cloud amounts which has both positive and negative feedbacks.

The effects of snow, ice, and increased water vapour are not uniform and lead to zonal and meridional temperature differences which generate circulations and transports which further modify the atmospheric and oceanic patterns so that the effect of uniform CO_2 increases can only be fully appreciated by consideration of the complete three-dimensional system. Virtually the only way to estimate the possible changes in the climate is through numerical models of the physical system. These models must first of all adequately simulate current climate with current CO_2 levels. An important test is the seasonal change of climate where mean temperature changes from summer to winter are about as large as the ice-age changes.

Model Characteristics

Surface energy budget models: these are highly simplified models which usually have latitudinal variations. They may have a parameterized treatment of land/sea effects and outgoing radiation, with albedo and heat transports parameterized in terms of surface temperature. They are useful in terms of qualitatively assessing major processes and effects.

One-dimensional (vertical) models: these models may have very sophisticated radiation schemes with high vertical resolution and they are very valuable in this regard. Adequate convective adjustment schemes can also be incorporated. They have no coupling of horizontal variations of

fluxes, cloudiness, ice cover and no albedo feed-back. Without these latter effects, it is not possible to estimate whether calculations are too high or too low.

Two-dimensional (vertical, latitude) models: these models generally have fairly sophisticated radiation (and photochemical) schemes. They may also have variable and coupled mean circulations, diffusion, ice and snow cover etc. hence, are valuable to study processes that are strongly latitudinal dependent. Unfortunately, there appears to be no way to properly parameterize the slantwise convection or eddy transports, the most important transports in the atmosphere. This makes an evaluation of their results difficult.

Three-dimensional models: these models can be made as complex and as sophisticated as one wishes. In practice they are strongly limited by computing power and by our understanding. The former is increasing at least as fast as the CO_2 , the latter much more modestly. The major uncertainties are in the required resolution of the dynamical and boundary layer processes; the physical simulation of clouds and sub-grid scale processes; and the effects of the disparity in time scales between the atmospheric and oceanic transports. Of these the most critical uncertainties appear to lie in distribution and effects of clouds and in ocean storage and transport of heat.

Model Results

Most results are given for a doubling of CO_2 and have been summarized by Stephen Schneider (1975). The results range from 2.9°C to 0.7°C increase in globally averaged surface temperature in response to a doubling of CO_2 .

The uncertainty due to cloud effects exists in all these models and has yet to be resolved. A step-forward in oceanic effects has been made at Geophysical Fluid Dynamics Laboratory in Princeton by incorporating an upper mixed-layer ocean of 90 m depth with a heat storage mechanism but no transports. J. Smagorinsky has privately communicated the following results of an unpublished simulation experiment by Manabe & Stouffer (Figure 6). In this experiment the CO_2 was increased by a factor of 4.

- 1) It takes of the order of 10 years for the combined mixed-layer ocean and atmosphere system to settle down to a new climatic state. If the mixing between the surface and deeper layers of the ocean were taken into account, about 50% to 75% of the total change would occur in 10 years; the remainder of the change would take much longer.
- 2) The global average increase of surface temperature is about 4°C . (The corresponding 2X CO_2 increase with this model yields a 2°C increase).
- 3) The annual mean change is smallest at the equator (3°C) and greatest at the poles: 6°C at the South Pole and 9°C at the North Pole.

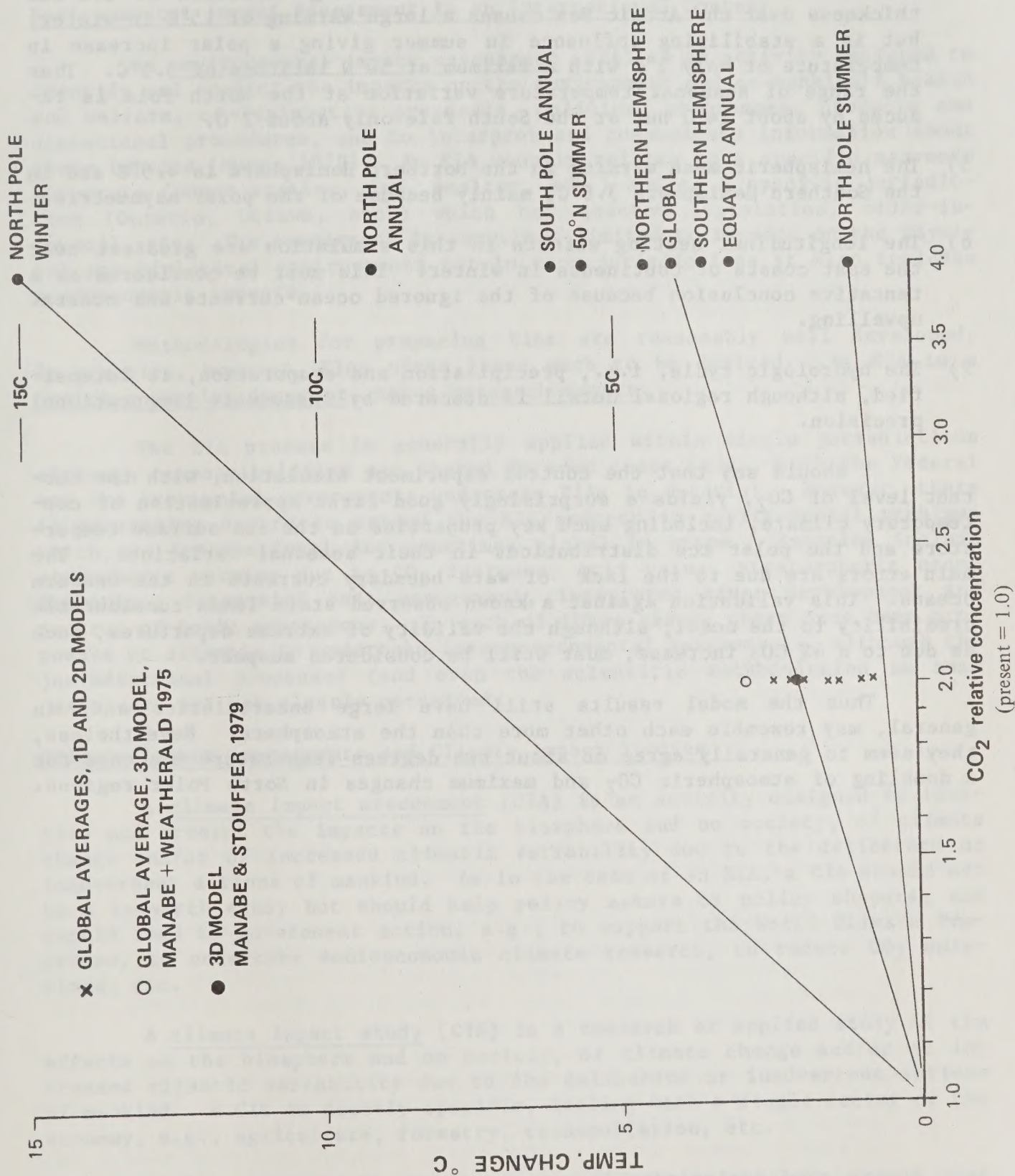


Figure 6 Temperature change of model climates due to changes in CO₂ concentration.

- 4) The asymmetry of response between polar regions is very extreme with season, in this simulation because a 4X increase in CO_2 just melts the North Polar sea ice in summer only, whereas most of the Antarctic snow cover remains year round. The resulting reduction of sea-ice thickness over the Arctic Sea causes a large warming of 15°C in winter, but is a stabilizing influence in summer giving a polar increase in temperature of only 1°C with a maximum at 50°N latitude of 5.5°C . Thus the range of seasonal temperature variation at the North Pole is reduced by about 14°C but at the South Pole only about 2°C .
- 5) The hemispheric mean warming in the Northern Hemisphere is 4.5°C and in the Southern Hemisphere 3.6°C , mainly because of the polar asymmetries.
- 6) The longitudinal heating effects in this simulation are greatest near the east coasts of continents in winter. This must be considered as a tentative conclusion because of the ignored ocean currents and coastal upwelling.
- 7) The hydrologic cycle, i.e., precipitation and evaporation, is intensified, although regional detail is obscured by inadequate computational precision.

I should say that the control experiment simulation, with the current level of CO_2 , yields a surprisingly good first approximation of contemporary climate, including such key properties as the sea surface temperature and the polar ice distributions in their seasonal variations. The main errors are due to the lack of warm boundary currents in the western oceans. This validation against a known observed state lends considerable credibility to the model, although the validity of extreme departures, such as due to a 4X CO_2 increase, must still be considered suspect.

Thus the model results still have large uncertainties and, in general, may resemble each other more than the atmosphere. Nevertheless, they seem to generally agree on about two degrees temperature increase for a doubling of atmospheric CO_2 and maximum changes in North Polar regions.

THE FRAMEWORK FOR A CLIMATE IMPACT ASSESSMENT

BY

R.E. MUNN

Environmental Impact Assessment in an International Context

An environmental impact assessment (EIA) is an activity designed to identify and predict the impacts on the environment and on mankind's health and welfare, of legislative proposals, policies, programmes, projects and operational procedures, and to interpret and communicate information about these impacts (Munn, 1979). An EIA usually relates to a specific man-made structure (power station, dam, smelter, etc.) and to a specific jurisdiction (Ontario, Ottawa, etc.) which has enacted legislation, order-in-council, etc. The assessment is sometimes limited to impacts on the physical and biological environments but in many jurisdictions it also includes socioeconomic impacts.

Methodologies for preparing EIAs are reasonably well developed. In practice, however, EIAs often leave much to be desired. An EIA is a decision-shaping document, not a research report.

The EIA process is generally applied within single jurisdictions although responsibilities are shared in some cases (e.g., both the Federal and the Provincial governments undertake EIAs in Ontario). However, there is increasing desire to extend the EIA process to environmental problems which are international and sometimes global in scope. Examples include atmospheric warming due to CO₂ increase, acid rains, stratospheric ozone depletion, integrated pest management, integrated river development and control of toxic substances. In each of these cases, there have been proposals or attempts to undertake intergovernmental assessments, although the jurisdictional processes (and even the scientific methodologies in some cases) are not yet clearly perceived.

Climate Impact Assessments and Climate Impact Studies

A climate impact assessment (CIA) is an activity designed to identify and predict the impacts on the biosphere and on society, of climate change and/or of increased climatic variability due to the deliberate or inadvertent actions of mankind. As in the case of an EIA, a CIA should not be a research study but should help policy makers or policy shapers, and should lead to government action, e.g., to support the World Climate Programme, to undertake socioeconomic climate research, to reduce CO₂ emissions, etc.

A climate impact study (CIS) is a research or applied study of the effects on the biosphere and on society, of climate change and/or of increased climatic variability due to the deliberate or inadvertent actions of mankind. A CIS is usually specific, dealing with a single sector of the economy, e.g., agriculture, forestry, transportation, etc.

With respect to CO₂ warming, many climatologists have argued that since there is insufficient knowledge to prepare a CIA, the emphasis in the next 5 years should be directed towards CIS's. This view can be challenged,

however, on the grounds that without a CIA framework, CIS's may be solving interesting problems which are irrelevant in the context of national and international policy formulations. Scientists tend to solve easy problems that are well bounded, particularly in the case of interdisciplinary studies.

The central point of this paper is that a CIS can only be undertaken successfully in the framework of a CIA.

The Elements of an ETA

As outlined in Munn (1979), an EIA should:

- a. describe the proposed action as well as alternatives;
- b. describe the relevant components of the present environment including socioeconomic factors;
- c. estimate the nature and magnitude of the likely environmental changes (both natural and man-induced);
- d. identify the relevant environmental concerns, and the groups of people having these concerns;
- e. define the criteria to be used in measuring the relative significance of project-induced environmental changes;
- f. estimate the significance of the predicted changes, i.e., estimate the impacts of the proposed action;
- g. make recommendations for acceptance of one or more alternatives, or rejection.

In some jurisdictions, the EIA does not include item (g), recommendations.

The Elements of a CIA for CO₂ Induced Warming

The following outline for a CO₂ induced warming CIA is tentative and is offered as a basis for further discussion.

- (a) The CIA should include a description of relevant past and present environmental conditions and trends, separating the natural from the anthropogenic components, and further separating the several anthropogenic factors (CO₂, particulates, fluorocarbons, etc.). Time and space resolutions should be identified.
- (b) An estimate should be made of present biogeophysical and socioeconomic impacts (if any) including identification of the affected parties. (Who is losing? Who is gaining?) (There are probably no economic losses as yet. Are there economic gains resulting from CO₂ releases from fossil fuels, and from forest clearing? Can these be quantified?).

- (c) A selection should be made of several alternative management strategies, including that of doing nothing. (These strategies will involve only incremental changes. Nothing major will be achieved quickly.) This is a critical step in the analysis.
- (d) For each alternative, an estimate should be made of the biogeophysical changes and then of the socioeconomic benefits and disbenefits both over the short and long terms, clearly identifying the affected parties. Here it should be noted that society's resilience to climate variability and change is decreasing. (See SCOPE-AES Workshop Report on Climate-Society Interfaces.)
- (e) A sensitivity analysis should be undertaken, leading to estimates of the ranges of uncertainty at each stage in the analysis and in the final comparisons of alternatives.
- (f) Recommendations should be made, e.g., with respect to filling knowledge gaps, reducing emissions, etc.
- (g) Finally, the results should be presented in non-technical language in only a few pages.

Some of the actions that could be recommended include the following:

1. reduce the rate of increase in CO₂ emissions, e.g., emphasize nuclear energy development;
2. increase the strengths of the sinks;
3. reimburse adversely affected parties;
4. protect adversely affected parties, e.g., grow drought-resistant crops, make artificial snow for ski resorts, etc.;
5. establish priorities for socioeconomic studies;
6. redesign existing studies of the carbon cycle and of climate warming to meet the socioeconomic requirements (existing research may not be providing the best kind of information for policy analyses);
7. develop a common interdepartmental or intergovernmental awareness of the issues involved and the priorities required;
8. keep options open.

In each case, costs, benefits and the uncertainties in cost-benefit analyses should be estimated. Here as elsewhere in this paper, costs and benefits include social as well as economic ones.

Some General Comments

- a. A CIA for CO₂ induced warming should not be an advocate/adversary document, should not be clouded with irrelevancies and should not be a compendium. The CIA should be helpful to policy makers, who

will use the document to decide whether the benefits outweigh the disbenefits.

- b. Forecasting climate change is difficult but forecasting socioeconomic impacts is even more difficult. Society is never in a steady state, values change in both time and space, and past experience is not reproducible.
- c. although socioeconomic forecasting will be almost impossible, yet there is need for long lead times to avoid irreversible atmospheric effects. When the impacts on climate become detectable, it will already be too late for human intervention.
- d. Because of the uncertainty involved, it is undesirable to use assessment strategies that tend to lead to consensus amongst the assessors (in the same discipline but in different countries; in different disciplines in the same or different countries). The alternative is to employ adaptive strategies (Holling, 1978; Munn, 1979) that do not foreclose options even though they are sub-optimal and/or more costly over the short term.
- e. The initial effort should be devoted towards developing a policy analysis framework for a CIA. Then resources can gradually be shifted to case studies, e.g., CIAs for agriculture, transport, offshore exploration, etc. To begin with case studies will lead to a blurring of the ultimate goals and objectives of a CIA.

Conclusion

The institutional and methodological frameworks for EIAs are reasonably well developed, although the assessments produced in practice are admittedly far from perfect. This paper argues that some of the ideas that have evolved within the EIA process may provide a useful framework for national and intergovernmental impact assessments of atmospheric warming due to a CO₂ increase.

WORKING GROUP

REPORTS AND RECOMMENDATIONS

Working Groups

Group I Carbon Dioxide Balance

Chairman - F.K. Hare
- R. Burling
- W.R. Cummins
- R. Overend
- J. Padro
- K. Pettit
- M.L. Phillips
- J.M. Powell
- G.R. Williams
- C.S. Wong

Group II Energy Scenario

Chairman - F. Belaire
- E.R. Brushett
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- D.G. MacDonell
- E.F. Roots
- P.R. Scholefield
- R.G. Skinner
- D.H. Slade

Group III Climate Models

Chairman - B.W. Boville
- G.J. Boer
- T. Gal-Chen
- P. Jones
- P.E. Merilees
- S. Smith
- R.K.R. Vupputuri
- S.F. Woronko

Group IV Socioeconomic Impacts

Chairman - R.E. Munn
- M.O. Berry
- B.E. Goodison
- K. Higuchi
- D. Liverman
- G.A. McBean
- G.A. McKay
- D. Sewell
- R. Skinner
- P. Timmerman

CARBON DIOXIDE BALANCE

Upon what should our Working Group report? The Workshop Chairman suggested that we address the following questions: -

1. What contribution to the overall cycle occurs due to processes at work in Canada, or in Canadian marine waters?

The first question should allow a fairly direct answer. As regards the land biota, Canada has about one-quarter of the Boreal Forest formation, which contains about one-eighth of all plant biomass on earth. We also have smaller amounts of deciduous forest, temperate evergreen forest and grassland. It should be quite easy to make an estimate of the total contribution the land biota makes to the photosynthesis and respiration totals for the world. It should be of order of 3 percent, unless the basic arithmetic is wrong. Has anyone done this arithmetic more accurately? Do we have estimates of carbon exchanges within Canadian waters? What is our fossil fuel consumption and burning of wood? Have we estimates of the carbon content of our soils and muskegs, and of changes due to cultivation and forest clearance?

2. What unique opportunities or responsibilities does this impose upon Canadian scientists?

We make a fairly small contribution to the fossil fuel consumption, but have a major role to play in forest and soil transfers. We should lay heavy stress on getting better estimates of biomass and net production from our major formations, especially the Boreal Forest, tundra and prairies, and complementary estimates of soil and litter storage, plus the status of our muskegs. However, what special role might the marine sciences play?

3. What capabilities do we have to respond to (2), and what is now in progress, or planned?

A major purpose of the Workshop is to answer this one. There are significant efforts in several federal departments and universities. We should compile a list, and recommend possible extensions.

Canada's Role in the Carbon Cycle

Because Canada's land area and adjacent seas are so large, she plays a critical role in the world-wide carbon cycle. All other countries have a vital stake in our attempts to understand that role. And Canada herself stands to gain from a full understanding, since many of her productive farmlands, forests and fisheries lie in climatically marginal areas. Adverse changes in the climate may hurt Canada badly. Adequately forewarned, however, she might exploit the impending changes to her own benefit.

The natural vegetation of Canada includes prairies, mixed forests, Boreal coniferous forests and tundra. Of these, the Boreal forest is by far the most extensive. Of the total plant carbon storage on earth (about 830 gigatonnes of carbon, or Gt of C), one-eighth, or 108 Gt of C, is thought to lie in the Boreal forest. Canada's share in this is at least one-quarter. One estimate (due to Ralph Overend) is that Canada's forests as a whole (including the non-Boreal regions) store 44 Gt of C, over one-fifth of estimated world storage by natural vegetation. Moreover, 38 Gt of C may also be stored in the form of peat, with unknown further amounts in soils and forest litter. The tundra lands of the arctic are less rich in stored carbon, but they cannot be neglected.

A significant fraction of the world total of carbon stored in natural ecosystems, therefore, lies within Canada, and is accessible to Canadian research workers. Because of the short, cool growing season, the annual exchange with the atmosphere is less than might be expected, but it is still very large. Hence Canada stands alongside the Soviet Union, Brazil and the United States as custodians of very large proportions of the world storage of carbon by vegetation, soils and bogs.

This imposes both a challenge and an obligation upon Canadian scientists. It is a challenge because a small scientific community is confronted with the very big job of assessing these large problems. And it is an obligation because reliable world estimates cannot be made without good data from Canada. At present these data are lacking.

Much the same is true of Canada's performance in the marine area. There is significant skill in carbon cycle research in Canada's marine laboratories, both governmental and academic. Little priority has been given so far to such research, because other problems have loomed large. As regards the atmosphere, where carbon dioxide plays a major role chemically and physically, a good beginning has been made with monitoring and model development. But the scale of effort has been small -- though Canada lies beneath no less than 10 million square kilometres of active, carbon-bearing atmosphere.

Carbon Cycle Research in Canada: Recommendations

A considerable amount of research on different aspects of the carbon cycle has been carried out in Canada, but it has been scattered between several disciplines, many different centres, at different periods. No attempt has been made to bring it together. We consider that this situation must be remedied quickly, and offer a series of recommendations to help the country move in the right direction.

GENERAL RECOMMENDATIONS

Recommendation 1. A comprehensive analysis of the carbon cycle within Canadian land, sea and air should be a central part of the Canadian Climate Program. (This view is consistent with the plans for the World Climate Programme, and with the U.S. Climate Program. Obviously the analysis must be interdisciplinary, and will call for work by many different public and private agencies).

Recommendation 2. An effective coordinating mechanism -- presumably an interdisciplinary, interagency committee -- will be needed to coordinate Canadian research on the carbon cycle to ensure the free flow of information between groups involved.

Recommendation 3. All work on the carbon cycle in Canada should relate as closely as possible to international programs planned or in progress. Close liaison should also be maintained with national programs in suitable countries, such as the U.S., the Scandinavian countries, Finland and the Soviet Union.

MONITORING

Because we cannot yet predict the behaviour of the carbon cycle from theoretical considerations, it is vital to monitor the key storages and transfers between reservoirs, wherever the technical means exist.

Canada already monitors atmospheric carbon dioxide concentration at the following sites:

- i) Alert, N.W.T.
- ii) Sable Island
- iii) Ocean Weather Ship (OWS) Papa

This appears an adequate level of monitoring, as long as the Ship Papa series is maintained. The loss of continuous information from Weather Station Papa would be a serious blow to the national effort, and would also seriously weaken international study.

Recommendation 4. The above monitoring program, including the Ship Papa series, should be maintained.

Considerable skill exists in Canada in the direct measurement of the flow of carbon dioxide upward and downward over natural surfaces, including lakes and oceans. We believe, however, that it will be hard to apply such techniques to the monitoring of fluxes on a long-term basis, and do not recommend such a course over most surfaces.

Nevertheless, efforts should be made to approach a better understanding of the role of Canada's marine areas in the carbon cycle. Observations of the effects of marine biota and of carbonate chemistry are necessary to understand the oceanic control of atmospheric carbon dioxide levels. Suitable observations are already underway at OWS Papa. If this station is abandoned alternative means to continue these studies will be needed.

Recommendation 5. All monitoring of gaseous and liquid-phase carbon dioxide levels and transfers requires scrupulous attention to calibration and reference to international laboratory standards. These standards should be maintained.

BIOTIC PROCESSES

It is important that the stored carbon content and net annual production of new biomass be estimated for each of Canada's major ecosystems. Very few such determinations have been made in sufficient detail. The Truelove Lowland Tundra Biome study, and the Matador Grassland Biome project during the IBP, were landmark studies. They showed, however, that it is very costly and difficult to undertake studies in enough depth to establish regionally representative estimates, either of standing crop or of net production. Such studies must be intensified in future, as soon as adequate resources and methodology can be made available. Meanwhile there are certain specific steps that should be taken at once.

One such measure is to modify the Canadian Biomass Program of the National Research Council of Canada. This is an interagency project designed to determine whether or not natural biomass production could make a significant contribution ($>1\text{EJ} = 10^{18}\text{J}$) to the national energy supply post 2000. Current biomass energy is around $3\frac{1}{2}\%$ of the total, and is expected to rise to 5% before 1990. The program (designed to end in 1985) will estimate biomass productivity and inventory, nutrient depletion and environmental impacts, together with harvesting and conversion technologies. The current emphasis is on the conversion of current forest inventories to biomass data.

Recommendation 6. The Biomass Program should be modified so as to provide direct information concerning the stored carbon and rates of natural fixation for as many sites and environmental conditions as possible.

Recommendation 7. Estimates should also be made of the volume, carbon content and oxidation/growth states of Canadian peat deposits (including rates of post-glacial accumulation).

Recommendation 8. The special role of fire in accelerating the transfer of biotic and soil carbon to the atmosphere should be examined in depth.

Recommendation 9. Canada should acquire sufficient capabilities in isotope methods needed for CO_2 research. The $^{13}\text{C}/^{12}\text{C}$ ratio and ^{14}C content in tree rings and other organic materials offer valuable insights into the rates of carbon accumulation and release. Oxygen-isotope methods also have much to contribute, especially in the analysis of marine sediments.

Recommendation 10. Encouragement should be given to attempts to develop models of the overall carbon cycle, and to render such models compatible with the ocean-atmosphere models now being developed.

SOILS

The storage of carbon in the world's soils is one of the largest reservoirs capable of ready transfer to the atmosphere. In Canada the most important storage occurs in the litter and humus of the forest soils, in the rich but diminishing humus of the Prairie farmlands, and in the large bogs of north-central Canada (see Recommendation 7 above).

Recommendation 11. Estimates should be made as soon as possible of the storage and annual rate of exchange of carbon in Canadian soils, with major emphasis on

- (i) agricultural soils, especially as to the effects of farm practice on carbon levels;
- (ii) litter and soil storage in the major forest formations; and
- (iii) the carbon content and rates of recovery of burned-over and cut-over forest soils (see Recommendation 8 above).

OCEANS AND SEAS

Apart from the need to develop monitoring procedures for marine and fresh water systems, there is a crucial need to understand the mechanisms whereby carbon is transferred to and from long-term storage in the oceans. Canada's substantial expertise in ocean sciences makes possible a significant contribution.

Recommendation 12. Efforts should be made towards a better understanding of ocean mixing processes, and of other modes of downward transfer of carbon from the surface waters of the ocean. The mechanisms of downwelling and mixing to moderate and bottom depths require much attention.

Recommendation 13. Attention should be given to the further use of geochemical tracers and isotope methods in such research, particularly as regards oceanic tritium and helium. The Pacific and Arctic waters should be investigated using such techniques.

ENERGY SCENARIO

Introduction

The Energy Scenario Group interpreted its task as broader than dictating an energy base case to drive the deliberations of the other groups in the Workshop on Energy/Carbon Dioxide Issues and Impacts. It set out to explore the complex relationship between energy and climate. There was general agreement on the broad orders of magnitude that would characterize world energy futures, so the group concentrated on establishing rough boundaries of fossil fuel usage. It then turned its attention to the need for a policy framework to cope with the implications of the climatic effect of this range of fossil fuel use. Emphasis was placed on enhancing the capacity for policy response under conditions of uncertainty and change in the state of our knowledge about the linkage between CO₂, climate and energy activity. The group concluded that there was an urgent need to supplement and clarify knowledge about the impact on climate of the observed build-up in atmospheric CO₂, the extent to which these changes are a consequence of human action, especially energy related activities, and how best to influence or adapt to the climatic consequences of such changes. These conclusions led the group to suggest a matrix of recommendations to deal with uncertainty and to reduce uncertainty in the interests of Canada and the world.

World and Canadian Energy Futures

The doubling of the world's population and the concentration of that growth outside the boundaries of the now-developed world will be a principal factor in the world's incremental requirements for energy. So will the dynamic economic growth of the emerging countries, such as those of the Middle East and Latin America, which are expected to grow at twice the rate of developed countries. The slower growth countries of the Indian sub-continent and Africa, south of the Sahara, will place important new demands on world energy as their populations already exceed the carrying capacity of their traditional non-commercial forms of energy. Future world requirements of the order of 30 terrawatts in the first quarter of the next century are reasonable under these assumptions. Meeting these levels of world energy demand will force a significant reduction in the market share provided by oil and gas and the substitution of other fossil and non-fossil fuels. The resulting carbon dioxide release to the atmosphere associated with world energy use could approximately double so that 9 gigatonnes could be released annually by 2025. The regional distribution of the production of CO₂ will shift in accordance with the changing geographic pattern of energy use. Variance in temperatures, whether related to CO₂ or not, are not likely to alter the world's energy balances in this time frame.

Canada's energy requirements need not grow as rapidly as the world's. Canada has a number of optional energy balances because of its broad and diversified energy resource endowments and its potential to transform energy end uses. These large degrees of freedom should allow Canada to give a proper weighting to the impact of resulting CO₂ emissions on the world's as well as Canada's climate.

Energy/Climate Relationships

The production and use of energy is the main known method by which human actions have resulted in an increase in carbon dioxide discharged to the atmosphere. The amount of CO₂ discharged is increasing annually, at about 4%/year. The net increase in CO₂ remaining in the atmosphere, and the processes by which the increased amount discharged is accommodated by world-wide natural processes, appears capable of causing important changes in climate. Thus, there appear to be reasons to suspect a direct correlation between human uses of fossil and living organic fuels and CO₂-related climate change. The processes of climate change, and their consequences, are, however, much broader and more pervasive than the influences of use of different kinds and amounts of energy. Similarly, the amounts of energy, and the different kinds of energy resources and technologies used, are themselves, in Canada and elsewhere in the world, in part a response to climatic factors. Thus, the need for understanding and research on CO₂ and climatic variation cannot be determined by our present and future supplies and uses of energy; instead, the likely use of energy, and the energy options open to Canadians and the rest of the world, are factors in our understanding of the causes and effects of future climatic change, in our ability to continue to live well, with maintained or increased social freedom and economic strengths, in the climatic conditions of the future. Knowledge of how the climate is changing, by both natural and human actions, should not only enable unexpected climate-induced socioeconomic hardships to be avoided, but should enable changes in climate to be recognized, prepared for, and taken advantage of.

The relation between climate and energy has some aspects that are distinctively Canadian, some aspects which Canada shares equally with the rest of the world, and some aspects in which Canada is a passive but importantly-affected recipient of changes in other parts of the world. Canadian climate and geography dictate that in comparison with other parts of the world, we use a large proportion of our total energy for space heating and for transportation. They also dictate that we use a comparatively large amount of energy to exploit our biologically-marginal zones (northern prairies and boreal forests) for economic gain. In these areas, Canada's use of energy is very climate sensitive. But the sensitivity is not simple, for example, much of our agriculture is more moisture sensitive than degree-day sensitive, and if a CO₂-induced wavering of middle latitude climate carried a shift of precipitation patterns, the detrimental impact of a drying of the prairies could more than offset the benefits of a slight lengthening of the growing season. Under present technology this could only be compensated for by more energy-intensive farming. Similarly, most cities would welcome a somewhat warmer winter climate, but if that climate change brought greater snowfall, the increased winter urban energy budgets, mostly increased use of petroleum in transport, snowblowing, etc. could offset the savings in CO₂ emission connected with heating. The latter could have been met by a mix of less CO₂ intensive energy sources. Thus a milder winter could conceivably exacerbate, not lessen, urban contribution to atmospheric CO₂.

The energy options open to Canadians are to varying degrees climate-dependent. The gross pattern of energy supply geography and energy

demand geography is, in itself, to an important degree, a climatic response, as our concentration of population along the U.S. border, and the problems of supplying industrialized Ontario and Quebec with Alberta fossil fuels amply testify. One only needs to think of the problems of getting oil or gas from the Arctic Islands or Beaufort Sea to market to understand the degree to which present climate determines the economic viability of our resources. It is important to know whether, and to what degree, perturbations in climate that would reasonably be expected from CO₂-induced climate change would alter the economics; for example, a persistent reduction of 10% in winter sea ice cover could conceivably open the entire Sverdrup basin to icebreaker tanker traffic, possibly making available many hydrocarbon deposits that would not otherwise be economic.

The use of other energy options, to reduce our dependence on fossil fuels, is also climate-sensitive. The production of biomass is clearly dependent on both mean climate and climatic stability. Other renewable energy options, such as solar heating, are dependent on cloudiness as well as net radiation; our wind energy potential is very sensitive to local and regional perturbations of surface temperature.

It is, therefore, important that best possible understanding of the production of carbon dioxide from direct use of fossil fuels, and from the use of energy to alter land surfaces, and biomass which, in turn, affects atmospheric CO₂, be part of considerations of the importance and consequences of climate change. It is also important that the energy options open to Canadians, in terms of their ability to avoid hardship and prosper from climatic change, be part of our economic and social policies and energy strategies.

Variations Between Reasonable Scenarios of Fossil Fuel Usage

The probable intractability of the carbon dioxide issue is amply attested to by the rate and increase in the rate of the global use of fossil fuels. At present all fossil fuels are contributing over 5 gigatonnes of carbon dioxide to the global atmosphere annually. The rate of increase in the emission of CO₂ to the atmosphere is about 4.3% per year, a rate that has been maintained for much of this century except during periods of war or massive economic upheaval.

Heroic assumptions would be necessary to modify these historical use characteristics (see Figure 7 from W.P. Elliott of NOAA, unpublished). The central curve of the nest of three is simple extrapolation of the global carbon dioxide growth rate with the historical mix of fossil fuels. No change in biospheric input or the oceanic sink is assumed. A doubling at about 2025-2030 is indicated. The left most curve shows the effect of one of many possible extreme scenarios; a replacement of oil and gas by coal or coal-derived synthetic fuels. The right most of the three curves shows the result of a similarly extreme change in strategy; a major reliance on natural gas. The difference in the timing of the CO₂ doubling, even given such major strategic actions is barely a decade. Even as an extreme scenario as a cessation of any increase in the use of fossil fuels does not avoid a doubling but does delay consequences associated with a doubling until the 22nd century. In the absence then of any gross changes in the way that the

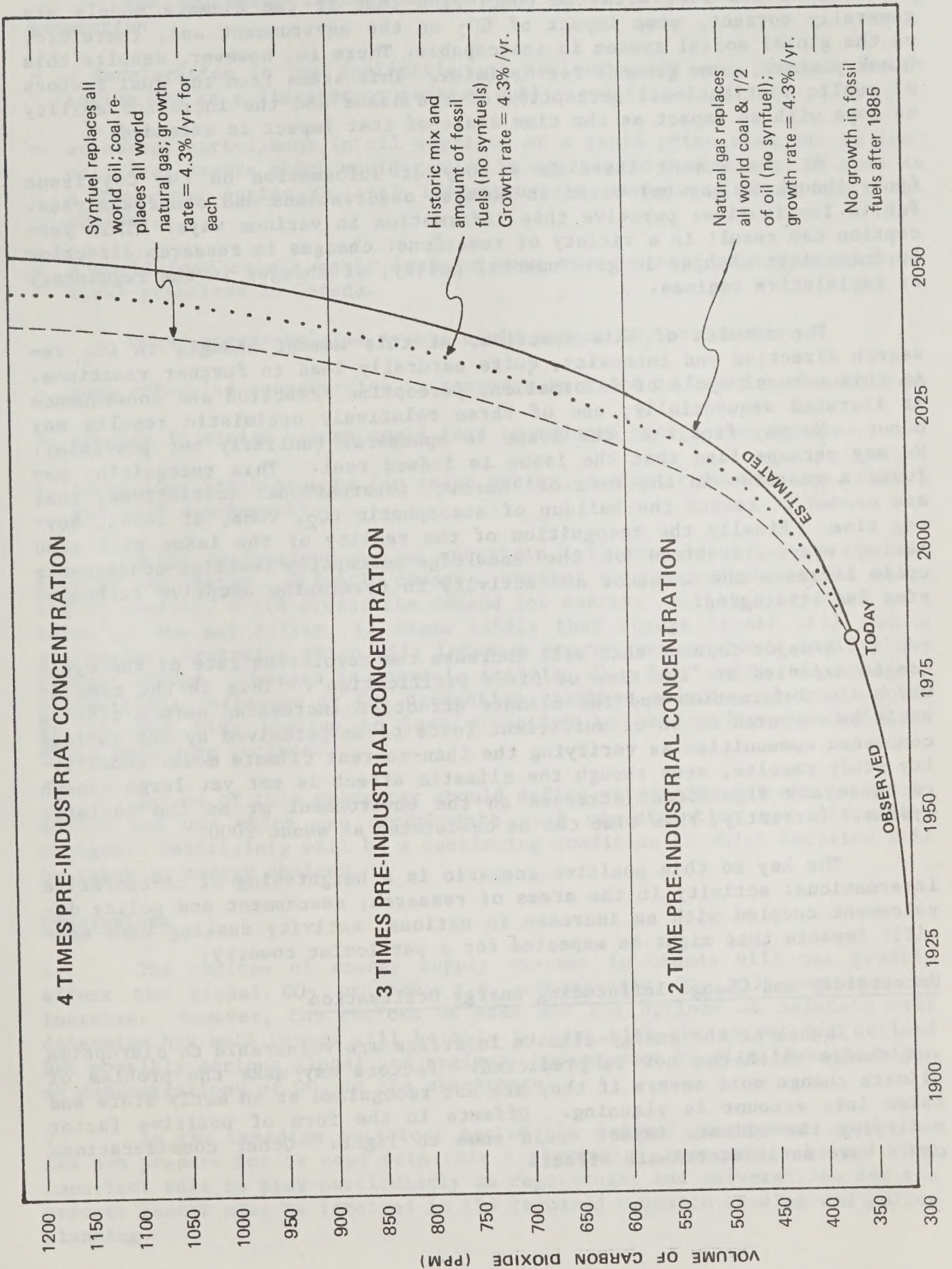


Figure 7
 SCENARIOS OF FUTURE FOSSIL FUEL USAGE (from W.P. Elliott, unpublished)

global atmosphere, biosphere and oceans partition the fossil fuel carbon dioxide, we are left with the conclusion that if the climate models are generally correct, some impact of CO₂ on the environment and, therefore, on the global social system is inescapable. There is, however, despite this bleak picture, some grounds for optimism. This stems from the dual factors of public institutional perception of the issue and the increased ability to cope with an impact as the time scale of that impact is extended.

At the moment there is a body of information on the CO₂ issue (poor though it may be) based on models, observations and other analyses. Public institutions perceive this information in various ways. This perception can result in a variety of reactions: changes in research direction or intensity; changes in governmental policy; or changes in the regulatory or legislative regimes.

The results of this reaction, at this moment changes in CO₂ research direction and intensity, quite naturally lead to further reactions. As this natural cycle of information, perception, reaction and consequence is iterated sequentially, one of three relatively optimistic results may occur. We may find that the issue is ephemeral (unlikely but possible). We may perhaps find that the issue is indeed real. This recognition may force a reaction in the form of 'heroic' international initiatives, that are needed to reduce the buildup of atmospheric CO₂, thus, at least, buying time. Finally the recognition of the reality of the issue will also during many iterations of the knowledge-perception-reaction-consequence cycle increase the interest and activity in developing adaptive technologies and strategies.

A major impulse that will increase the revolution rate of the cycle can be expected at 'the time of first verification'. This is the time at which the information and the climate effect of increasing carbon dioxide would be expected to be of sufficient force to be perceived by the various concerned communities as verifying the then-current climate model sensitivity study results, even though the climatic effect is not yet large enough to cause any significant stresses on the environment or on the societal system. Currently, this time can be calculated as about 2000.

The key to this positive scenario is a heightening of co-operative international activity in the areas of research, assessment and policy development coupled with an increase in national activity dealing with specific impacts that might be expected for a particular country.

Uncertainty and Change Influencing Energy Utilization

Issues of the energy-climate interface are vulnerable to disruption and change which can not be predicted. Factors may make the problem of climate change more severe if they are not recognized at an early state and taken into account in planning. Offsets in the form of positive factor modifying the climate impact could come to light. Other considerations could have an indeterminate effect.

The following factors could lead to an accelerated rate of CO₂ generation:

- a deceleration in the application of nuclear power or a nuclear moratorium due to a disaster or general public concern.
- an abrupt curtailment in oil supplies or a rapid price rise due to geopolitical events which would result in aggressive development of coal as a long-term option (a coal infrastructure emerging from crises, not choice).
- a world food crisis could lead to even more energy intensive agricultural practices in Canada.

Other energy-related events could reduce CO₂ production:

- more effective conservation in response to price or other considerations
- changes in social values could lead to reduced energy consumption.
- technology breakthroughs (in solar energy, fusion, communication, forest and land management).

Other disruptions are of uncertain influence depending on the nature of the change. Climatic changes, whether they represent overall warming or cooling, would affect the demand for energy. Although regional patterns of use may differ, it seems likely that change itself will induce protective strategies which will increase energy use and hence amplify the climate change. Changes in economic activity also fall under this category of uncertain influence on CO₂ production, perhaps reducing energy use but at the same time leading to less attention to the environmental factor which should be included.

Issues of this character should define strategies for energy development and use which can accommodate such uncertainties and disruptive changes. Uncertainty will be a continuing condition in which decision will be taken on energy choices.

Conclusions

1. The choices of energy supply systems in Canada will not greatly affect the global CO₂ problem, i.e. atmospheric CO₂ will continue to increase. However, the choices we make and the options we maintain will determine how well Canada will be able to cope with the as yet ill defined but possibly serious global and regional consequence of significantly higher concentrations of CO₂ in the atmosphere.

2. In the Canadian political system the federal government cannot on its own prepare for or cope with this - provincial governments have a very important role to play particularly as regulators, and universities and the private sector must be involved in the required research studies and policy planning.

3. The issue must be discussed amongst a broad constituency including
- academic community;
 - environmentalists and public interest groups;
 - public and private decision makers, in particular political decision makers.

The order and train of affects and perturbations appears to be:

Temperature change → other environment effects → economic impacts → social responses → necessitating political decisions.

To be able to focus enough attention to bring the required action as well as discussion with these specialists, information must be communicated to the public.

Recommendations

Attempting to describe future energy use, energy use patterns, energy climate interactions has illustrated many uncertainties in our understanding of likely or ever possible future events. This prompts two types of reactions. One, often the first that comes to mind, is to attempt to remove the uncertainty by pursuing research into the various socio-economic and physical-chemical processes involved. Examples include research into climate, attempts to observe man-induced climatic changes. Certainly this should be pursued, but in itself it will not be sufficient. We must at the same time be developing more resilient systems, we must attempt to deal with the uncertainty at the same time as we are trying to narrow the bounds of uncertainty. Canada has immediate interests based on the direct effects that may arise here as well as sharing an interest in the global problems and solutions. The following framework illustrates the four types of action.

	Canada's Particular Interest	Canada in a Global Context
Dealing with uncertainty	- agricultural research to develop crops viable under different climatic regimes - promoting energy conservation, more efficient energy use - research to prepare to cope with changes in water availability as a result of climate change, droughts or floods	- alternative energy sources, and systems - fusion, biomass etc.
Reducing uncertainty	- monitoring Canadian energy use (joining federal-provincial activity) to predict CO₂ production	- climate research - monitoring, looking for man-induced changes

CLIMATE MODELS

Monitoring of Atmosphere and Oceans

The effect of carbon dioxide on climate can only be assessed through the understanding of physical processes involving the major components of the climate system: the atmosphere, the oceans, and the cryosphere. Monitoring the dominant processes is essential for the development and verification of models. Monitoring the state of the three components is also required for detecting the actual effects of increasing CO₂ concentrations in the atmosphere.

Since global coverage is required for adequate monitoring of the climate system, observing systems based on satellite systems and technology are expected to play the major role in meeting vital observational requirements.

The study of critical and poorly understood climatic processes requires that particular emphasis be given to monitoring the ocean circulation and heat transports, snow/ice cover and thickness, the radiation budget (including associated parameters such as albedo and cloud cover), and the atmospheric moisture budget (including precipitation). To detect the actual effect of CO₂ on climate, special attention should be given to the long-term monitoring in the arctic and in the middle northern latitudes where the CO₂ effect is expected to be the most pronounced. The crucial parameters are the area and mass of the ice and snow, the albedo, the oceanic transports, the temperature, and the cloud cover.

It is recommended that Canada play a role in the implementation of future global monitoring systems through active international collaboration in the design and development of satellite observing systems, including satellite-interrogated surface stations. Also the integrity of those parts of the Canadian observing networks necessary for the assessment of long-term trends in surface and upper-air parameters must be maintained, particularly in the Arctic.

Diagnostic Studies in Support of CO₂ Modelling

An understanding of CO₂ impact on the physical climate system demands an understanding of the climatological budgets of the atmosphere, oceans, cryosphere, and land surfaces. It is important to consider these budgets both locally and on the synoptic scale for the hemisphere. Climate diagnostics are concerned with the 3-dimensional distribution of the variables which characterize climate and especially with the 3-dimensional budgets of heat, moisture (including cloud and precipitation), radiation, and energy. In particular these analyses may be applied both to real data and the output of climate simulation models. Diagnostic budgets on these scales are necessary to clarify the current climatological balance, to provide a basis against which to compare climate models, and to provide a basis against which to interpret impacts due to increased CO₂. New diagnostic methodology must be developed to assess the "significance" of simulated climate change due to increased CO₂.

Diagnostic study of climate in Canada has concentrated on applications of the surface climate record and on surface budget studies of energy, hydrology, and the cryosphere. Regional studies have been prominent. Some local ocean budget studies have been done as have special studies of climatological interest (volcano-temperature studies, Sahalien drought, etc.). These valuable efforts are continuing in government agencies and in the universities. There has been little "general circulation" climatological study done in Canada directed toward the large-scale global (or Northern Hemisphere) budgets. There have been no ocean general circulation climate studies of this kind prepared in Canada to our knowledge. Currently in AES, in conjunction with the atmospheric modelling activities, a general circulation diagnostic capability has been developed and is being applied to GCM output and observed data.

The resources required for diagnostic studies are also those required for the climate problem in general. In particular new activities are required in the area of large-scale ocean diagnostic budget studies. In the area of the cryospheric budget, an increased activity is necessary in observing and budgeting the cryosphere in northern latitudes on the large scale. Radiation budgets and moisture budgets which include cloud and precipitation would seem to require a cooperative effort with satellite observational activities. Current activities in atmospheric and surface climatological study should be supported, encouraged and expanded.

Climate Modelling for the CO₂ Issue

There is considerable scientific evidence that increasing the level of CO₂ in the atmosphere would cause an increase in global mean temperature at the ground. The evidence also indicates that the warming would not be uniform, but tend to be largest in the polar regions, most especially in the Arctic. Furthermore, significant climate anomalies on a regional scale would result from such a warming. The task of the scientific community is to determine when, where and how much of an anomaly would be produced. The only tools available to carry out this task are models of the climate system by which one can calculate the new climatic balances.

At the present time in Canada there exists a hierarchy of models which can and are being used to address the question. The Canadian Climate Centre (CCC) has available a one-dimensional radiative-convective-photochemical model of the type which has been used in the initial research on the CO₂ issue. There is expertise in the Atmospheric Research Directorate in the area of radiative transfer which will be important for the quantitative estimation of the warming due to CO₂ increases. McGill University has developed and experimented with a surface energy balance model which has been used to study the seasonal march of the energy exchanges. The CCC also has a two-dimensional model which has been used to address questions of the effect of increased CO₂ on the ozone balance. The University of Toronto also has expertise in this type of modelling and plans to use an extension of the simplified energy balance model to investigate the question of the existence of more than one possible new climate equilibria in response to CO₂ increase.

It is important that activity continue in the area of simplified models of the climate system. Such studies provide insight into the dominant physical mechanism and feedbacks which determine the sensitivity of the climate system. However, it is clear that the only tool which can provide soundly based quantitative information on the climate effects of CO₂ on a regional and local basis is a three-dimensional coupled ocean-atmosphere model. The Canadian Climate Centre has developed a three-dimensional model of atmospheric flow suitable for climatic studies and equally important has developed the capability for sophisticated processing of the results. At the present time, because of computer limitations the model is somewhat short of state-of-the-art, but could be rapidly improved in many areas. Interactive snow and ice cover are included, but in a relatively simple way. The crucial limitations in overall design with respect to the CO₂ question are the absence of interactive clouds and the absence of an interactive ocean.

A full dynamic and thermodynamic model of the world oceans coupled to the atmospheric climate model would be highly desirable, but appears impractical at this time both because of the very small scales of ocean "weather" and the paucity of data at depth. At the very least a model of the mixed layer of the ocean with heat storage and parameterized vertical mixing should be developed and coupled with the atmospheric climate model. Further development should include horizontal advection by mean surface currents and eddy diffusivity to represent transients. The physical oceanography community in Canada has the expertise to develop such models and ways must be found to organize their necessary collaboration with the climate modelling program.

Canada has demonstrated it has the required modelling skills and experience to implement and interpret the results of sophisticated 3D climate models. The major stumbling block is the level of computer resources. With presently available resources it is not possible to carry out climate experiments with a state-of-the-art model.

Data Sets

For modelling and diagnostic studies, global and hemispheric data sets defining the history of the states of the atmosphere, the oceans, and the cryosphere over the long-term are essential. Available data sets are generally deficient in one or more respects. Crucial factors are the adequacy and the consistency of the analysis methods, and the documentation of the methods used for reduction, quality-control, and analysis.

Operational numerical weather prediction centres such as the Canadian Meteorological Centre routinely produce analyses using sophisticated quality-control and analysis methods designed to assure physical consistency in time and in space, but due to existing operational priorities not all of the analyzed data is archived, nor are the archives necessarily designed to meet the requirements of climate research. Also, data collected from research and operational satellites is generally not analyzed or archived with climate research requirements. In general, the volume of data needs to be reduced by space filtering and by statistical analysis, and this is easiest to do in real-time as a by-product of operations.

Serious consideration should be given to the adjustment of the priorities of major operational centres to include activities in support of the development of high quality global and hemispheric data sets for climate diagnostic studies. In particular, collaboration between the national meteorological centres in such activities is desirable. Second, support should be provided for the development of quality-controlled and physically consistent data sets from existing archives. Third, international collaboration is required in satellite data reduction and analysis, so that adequate activities can be directed to the creation of filtered data sets for climate research.

Recommendations

1. Strong support is required for climate modelling. In particular a substantial increase in computer resources is required in order to exploit the existing Canadian climate model to provide quantitative estimates of global and regional climatic changes resulting from projected CO₂ increases. Computers up to the task are available and presently in use for these purposes in the U.S.A. and Europe.

2. Research support to universities and oceanographic centres in Canada must be increased to promote new activities in modelling of physical processes. High priority should be given to the study of cloud and ocean parameterization as related to climate modelling.

3. Diagnostic studies of the trends and budgets of the components of the climate system need to be strongly encouraged. In particular new activities are required in the area of large-scale ocean budgets and the cryosphere in northern latitudes. Such studies will necessarily involve international collaboration in the context of the World Climate Research Program.

4. Existing observational programs in the Canadian arctic and middle north must be maintained at a level which ensures the long-term monitoring of the climate in this crucial area. Further, Canada should play a role in the implementation of future global monitoring systems by active international collaboration in both the design and development of satellite observing systems and the subsequent data reduction and analysis.

5. A re-examination of the Canadian system of data analysis and archiving should be undertaken to ensure that the requirements for climate research are met both in a national and international context. Of particular concern is the development of physically consistent data sets from existing archives.

IDENTIFICATION AND ASSESSMENT OF SOCIOECONOMIC IMPACTS

Goal

The goal of the CCP activity in this area is to provide policy analysts with useful information, in the presence of uncertainty, on steps that should be undertaken immediately in the socioeconomic and technological fields with respect to a CO₂ induced warming of the atmosphere. The objective should be not only to seek ways to ameliorate unfavourable impacts but also to capitalize upon favourable consequences to the Canadian economy and life styles if atmospheric warming were to occur.

Importance of Socioeconomic Studies

The CO₂ program is important nationally and globally not only because of its intrinsic scientific interest but more importantly because of the possibility of important socioeconomic consequences of atmospheric warming. With increasing population and technology, the resistance of mankind to extremes in weather and climate is decreasing, and there is urgent need to plan ahead. If socioeconomic and technological studies are postponed until there is evidence of atmospheric warming, it will already be too late to reverse the trend or to take advantage of the socioeconomic opportunities that may accrue to Canada. In fact, a socioeconomic impact assessment framework should be developed as soon as possible. This will provide relevancy to the studies on the carbon cycle and on climate change in terms of the real needs of policy analysts and decision-makers.

Priority Setting in Socioeconomic Assessment

The impacts of CO₂-generated climate change can be considered in terms of a train of effects and perturbations:

TEMPERATURE CHANGE --- OTHER ENVIRONMENTAL EFFECTS ---
ECONOMIC PERTURBATIONS --- SOCIAL RESPONSES --- POLITICAL DECISIONS

Scientists deal with the first parts of this train. However, their funds often come from the last factor -- the political decision-making arena. Therefore, what needs to be done first is to identify how climate change will be important to politicians, certainly from their global perspective, but most importantly from their national and regional political orientation and responsibility or accountability. Why is the possibility of climate change so important to political leaders in Canada and why, then, should they appropriate resources to further study?

On a national and regional level Canadians will likely want to know first the economic perturbations, both positive and negative, generated by climate change. However impacts which are not primarily economic will also be of major concern. For example, "acid rain" has attracted considerable public attention because of its ecological consequences, and their implications to recreation. A major reason why priority needs to be given to identifying the nature of impacts is so that advice can be given regarding future strategies required to meet increasing energy demand. For example, coal and nuclear energy are the means most likely to be employed in meeting

the majority of this increase for the rest of this century. The identification of major adverse impacts associated with substantial increases in atmospheric CO₂ levels associated with coal and other fossil-fuel consumption would increase the desirability of the nuclear alternative.

What then, should the Canadian effort be in socioeconomic assessment of climate change? The following are suggestions:

1. Concerted monitoring of international research into climate change, and the adaptation of information and methodology to Canadian needs.
2. Based on the best available models of climate change, using reasonable scenarios, identification of regional impacts or effects that follow a "fault-tree" or probability assessment through the environmental-economic-social-political framework. These regional effects also need to be placed in a broader context. For example, what are the implications of a 2.5°C rise in temperature on the production and marketability of Canadian wheat? Or, what is the impact on fuel use and gas export. It follows that effects in other countries must be considered. It is important to focus on specific key economic sectors or "wealth-generators" in Canada, while at the same time recognizing that social implications cannot always be judged in purely economic terms.

The Elements of a Socioeconomic Impact Program

1. Major Impact Parameters

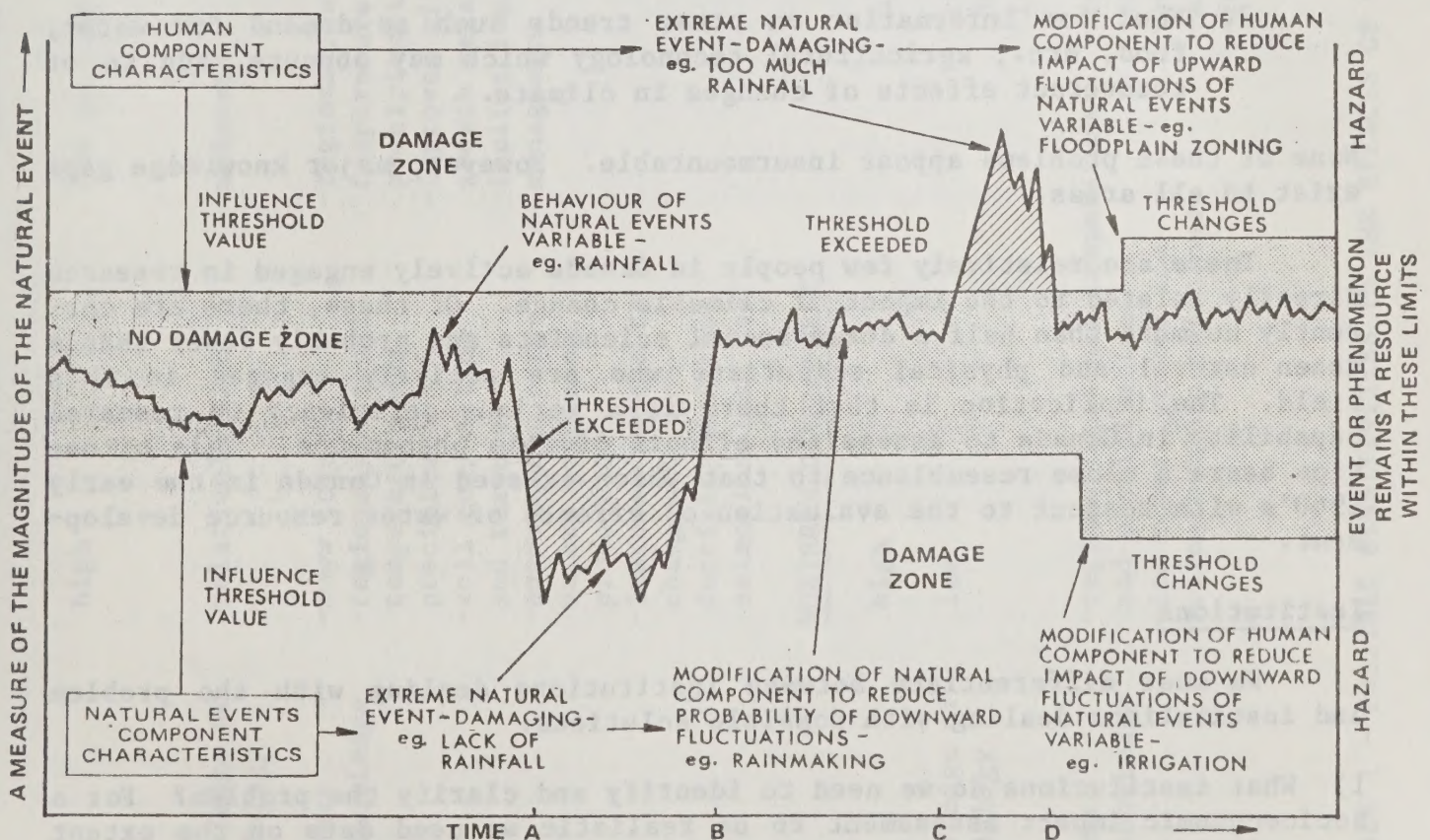
The atmosphere interacts with several other systems, both natural and human in character. Such impacts produce consequences which have environmental, economic, social and political implications. Identification of the specific impacts provides the information on the basis of which the political system can decide upon an appropriate strategy. The challenge is to develop a taxonomy of impacts embraced under each of the categories identified above. For example, in the case of environmental effects a change in the CO₂ content of the atmosphere might result in alterations in the volume and composition of various types of vegetation and wildlife or changes in the incidence of particular kinds of respiratory disease. If the change in CO₂ levels is sufficiently high, they are likely to result in a basic alteration in precipitation patterns, which in turn could alter agricultural potentials and possibilities of hydro-electric power development.

Each of these impacts will have differential effects regionally, provincially, nationally and internationally. The areal extent of the problem will be a significant factor in determining which level of administration should be responsible for initiating action. Research undertaken so far is much more advanced in the case of economic and some of the environmental parameters than it is with respect to the social and political ones. This is in part a reflection of the fact that the former are somewhat easier to identify and measure and to incorporate within an evaluation framework. However, it must be recognized that an assessment of the latter two dimensions may well be the area where policy makers most urgently require assessments.

Technology provides a means whereby certain of the adverse effects can be ameliorated or whereby advantage might be taken of changes in the CO₂ composition of the atmosphere. An important aspect of impact assessment, therefore, is an evaluation of likely developments in technology. With such an evaluation one would be able to define more accurately the range in which one might be able to deal with the impacts of given alterations in the CO₂ content. This latter point can be illustrated with reference to Figure 8 relating to adjustments to natural hazards, such as floods or droughts.

A final consideration is the distinction between perceived impacts and those which occur in reality. Research has shown that there are substantial variations among individuals and groups in the way in which they perceive and respond to natural phenomena and variations therein. This factor becomes extremely important in identifying and measuring impacts and it needs to be built in to the analysis. Although a number of workers have shed important light on this phenomenon, it has yet to be successfully incorporated into evaluation frameworks. The challenge is especially great in the case of aspects of the natural environment that are not directly visible or close to the perceiver. CO₂ in the atmosphere is an obvious case in point.

Figure 8 An Illustration of the Concept of Threshold in the Context of Hazards and Resources



(courtesy D. Sewell after Hewitt and Burton, 1971)

2. State of Knowledge about Socioeconomic Impacts

Table 1 is an attempt to analyse impacts by some of the important areas of Canadian activity. The list of sectors is by no means comprehensive. "Sensitivity" refers to the potential magnitude of the effects of changes in climate, related to increased "greenhouse" effect, on a sector. Except where noted, effects are assessed on a national basis, i.e. local and regional impacts may be considerably different. Also, impacts may be either beneficial or disruptive. It is important to note the use of the term "potential magnitude" here - no definitive assessment is possible in most instances until the nature of climate changes, and the functional relationships between these changes and social-environmental-economic factors, are better established. Important in this context is not only the magnitude of climatic changes but also the rate of change or, in other words, the rate at which society may need to adjust.

Overall the major problems identified in predicting the socioeconomic impacts of CO₂ include:

1. Need for improved models which allow variables such as agricultural production, energy consumption and recreation behaviour to be predicted from climatic parameters.
2. Need for accurate inputs into socioeconomic models in terms of spatial and temporal conditions of temperature, precipitation, snow and ice cover, and to a lesser extent wind and insolation.
3. Need for information on other trends such as demand for water, food, etc., agricultural technology which may obscure, add to or counteract effects of changes in climate.

None of these problems appear insurmountable. However, major knowledge gaps exist in all areas.

There are relatively few people in Canada actively engaged in research directly related to the impact of climatic change. Of these, there are currently no more than half a dozen social scientists and probably fewer than a dozen natural and physical scientists who are actively engaged in this field. The implication is that there is a serious deficiency in research capability in Canada to assess the effects of this phenomenon. This situation bears a close resemblance to that which existed in Canada in the early 1960's with respect to the evaluation of effects of water resource development.

Institutions

We must differentiate between institutions dealing with the problem and institutions dealing with possible solutions:

- 1) What institutions do we need to identify and clarify the problem? For a socioeconomic impact assessment to be realistic we need data on the extent and magnitude of possible future climatic changes. Most of the institutions needed to accomplish these tasks appear to be already in place within the CCP.

	<u>AGRICULTURE</u>	<u>FORESTRY</u>	<u>TRANSPORTATION</u>	<u>RECREATION AND TOURISM</u>
sensitivity	high	low to high	moderate to low except high in ice infested waters	varies by type
state of knowledge of impact methodology	relatively high	moderate	low	relatively high
some areas where significant knowledge gaps exist	-snow cover -regional/seasonal temperature and precipitation -soil composition and texture -non-weather parameters governing production -improved models re changes in productivity and crop selection/land use	-regional/seasonal temperature and precipitation -improved climate-tree growth relationships -implications to forest management	-temperature, wind and ocean currents which determine sea-ice cover -models of climate-ocean-sea ice interaction -transportation system design, especially in the North	-precipitation and temperature -snow cover -cloud cover -some improvement in weather-activity relationships -trends in leisure
	<u>NORTHERN DEVELOPMENT</u>	<u>WATER</u>		<u>FISHERIES</u>
sensitivity	high	high		moderate to high
state of knowledge of impact methodology	low	relatively high but deficient at high latitudes		low
some areas where significant knowledge gaps exist	-regional/seasonal temperature and precipitation -ice cover, ground ice -climate-biota relations	-regional/seasonal temperature and precipitation -snow cover -arctic hydrological regime -future demand		-temperatures, atmospheric circulation patterns, ocean currents, and ice cover -integrated aquatic resource models

TABLE 1 - POSSIBLE SENSITIVITIES TO THE EFFECTS OF CLIMATIC CHANGE AND THE PRESENT LEVEL OF KNOWLEDGE

2) What institutions do we need to translate this climatic problem into comprehensible and actionable impacts? This is the area in which institutional change may be beneficial. A mechanism whereby a 2°C change in overall global temperature (for example) can be translated into social, political, and economic impacts is recommended. One possibility is the addition to the Canadian Climate Centre (CCC) of social scientists and economists who would:

- i) translate climatic change into social and economic terms;
- ii) facilitate public information programs;
- iii) establish contacts with other groups in the intellectual community.

Appropriate funding might be derived from an advisory committee attached to the CCP which would provide liaison with other concerned agencies and scientific bodies.

3) What institutions might we need in order to adapt to, or to arrive at solutions to the problem?

Until we get more definite information we are not going to have major institutional changes. Reasonable boundary limits on scenarios may come with better information, and, at that time, the examination of particular institutions to identify possible modifications should be undertaken.

We should address ourselves in our recommendations to the next five years, developing the capability for socioeconomic impact assessment in Canada, tying this capability as closely as possible to existing scientific bodies. In this way we will be best prepared to make proper and acceptable assessments when the time comes.

Summary Recommendations

1. A program to increase public awareness and discussion is needed.
2. Expertise available to CCC should be expanded to include geographers, sociologists and economists.
3. A national advisory committee on impact analysis should be created.
4. The CCP should develop a framework for establishing priorities for research and development directed to the assessment of climatic change and its impacts, primarily in relation to potential effects on Canadian society.
5. Using the above-mentioned framework, resource requirements need to be established and decisions made regarding their distribution, e.g. in-house, grants, contracts.
6. Better interaction is needed between those scientists concerned with climatic processes and impact analysts in order to establish the needs of the latter group for climatic inputs to socioeconomic analysis.
7. In view of the international nature of the CO₂ question, close liaison with concerned agencies in other countries and with international agencies such as UNEP, ICSU is needed.

SUMMARY COMMENTS

The complications of man-induced climatic change, both positive and negative, make imperative its consideration in policy and planning. The effects of carbon dioxide increases on climate will be gradual and the perception of change for some time to come may not be great. Nevertheless the ultimate effect could alter agriculture, settlement, transportation, water and other renewable resources irreversibly, and should be considered globally in today's decisions regarding major capital works and regional development. The time scale for the introduction of alternative energy technology requires that consideration be given now to the potential consequences of increased atmospheric carbon dioxide.

At the Workshop no attempt was made to assess the effects of climate change on the Canadian economy and institutions. However, the present level of Canadian understanding and effort was assessed with a view to proposing action where major gaps are apparent in understanding and application. Overall there was consensus that:

- the level of atmospheric carbon dioxide is increasing and will continue to increase over the foreseeable future. The levels are controlled by activities and processes which are global in scale and mainly external to Canada;
- how Canadians cope with future climate change is extremely important. Changes of global mean surface temperature of one or two degrees Celsius or of regional precipitation patterns can have major socioeconomic consequences affecting areas such as: land and water transportation systems, settlement patterns, resource management, water supplies and regimes. Knowledge that such changes may and probably will occur is required now for the design of infrastructures and enterprises whose viability depends on economic operations over the longer run;
- fossil fuels are the major but not the whole source contributing to this increase. Canadian energy use will not be decisive in determining the future levels of atmospheric carbon dioxide;
- the oceans and land biota play important roles in determining the carbon dioxide levels within the atmosphere. A significant fraction of the global biomass and oceans are located in Canada;
- major knowledge gaps exist relative to the processes that control the levels of atmospheric carbon dioxide as well as to the capacities of carbon sources and sinks. Equally, major knowledge gaps exist on the understanding of how the climate system is and will be affected, and the socioeconomic consequences of such changes;
- an ability to accurately predict climate is needed. Furthermore, the monitoring program must be developed. The greatest surface temperature changes due to increasing atmospheric carbon dioxide will occur in high latitudes, and monitoring of the climate and its manifestations in these latitudes will provide the best signals of change;

- excellent scientific capability exists within Canada, but little of its present effort is directed toward understanding and predicting the consequences of climatic change.

Implications for the Canadian Climate Program
(as perceived by the editorial review board)

The above consensus convincingly confirms that the Canadian Climate Program must, on a priority basis, incorporate activities in climate understanding, monitoring, prediction and impact assessment relative to changes in atmospheric carbon dioxide. Furthermore, since the need for this information is in support of decision making for energy use on a global scale, and development and resource planning on the national scale, the Canadian Climate Program must embrace the climate-related activities in energy, transportation, agriculture, fisheries and many others that influence policy and planning. These steps are essential if Canada is to achieve optimal use of its climate resources. The required level of effort demands major institutional and computing support beyond that now provided in Canada.

It is important that research on the carbon cycle and its climatic relationships be carried out in Canada. There is a real advantage in scientific research that is dedicated primarily to Canadian interests, and progress is enhanced when there is a ready exchange between research scientists. Furthermore, Canada needs the security afforded by a climate modeling capability. Access to foreign research can become difficult if the results are likely to be embarrassing or advantageous to the donor country. Other countries tend to exploit scientific advances to their national advantage. We should be in a position to do the same by maintaining an independent research effort on various aspects of the carbon cycle.

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ANNEX 1

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Long-range transport climate change

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Studies on Devon Island Ice Cap as indicators of climate change

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Direct measurement of CO₂ gas flux between ocean and atmosphere. Alkalinity measurements within ocean (gives pCO₂)

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General

ANNEX 2

The U.S. Department of Energy Carbon Dioxide Effects Research and Assessment Program

Recognizing the potential importance of the carbon dioxide issue to the policy requirements of the National Energy Organization Act of 1977, a carbon dioxide effects research and assessment program was initiated in the Office of the Assistant Secretary for Environment, DOE. The program, begun in 1978, was conceived of as a multiyear effort with an overall assessment and analysis occurring in 1984 and 1989. The goal of this national research and assessment effort is to develop the ability to predict the environmental, agricultural, economic, social, and political consequences of the increasing atmospheric concentrations of carbon dioxide with sufficient confidence to permit policy decisions to be made on the future global use of fossil fuels.

Three strategies were adopted in order to begin the extraordinary effort required to address this unprecedented problem. They were:

1. To begin the creation of a national and international focus for the carbon dioxide effects issue.
2. To act as a lever to assure adequate funding of the scientific community for the conduct of an unprecedentedly interdisciplinary national and international research effort.
3. To conduct the information synthesis and analyses required to provide predictions of social costs required for policymaking and to determine mechanisms for increasing the confidence in those predictions.

The Department of Energy created an institutional structure to provide the initial focus for the program. The roles of the elements of the structure are:

1. Carbon Dioxide and Climate Research Division. To develop and direct the DOE Carbon Dioxide Research and Assessment Program.
2. Science Directorate. To participate in planning the Program and to serve as the liaison between the scientific community and the DOE.
3. Integration and Assessment. To plan and execute the Assessment Program.
4. Advisory Committee. To provide independent advice to the Assistant Secretary for Environment and the Program on the conduct, plans, and management of the program.
5. U.S. National Climate Program Office. The national focus for United States climate programs recently created by the National Climate Act.

The DOE set out to create a science plan of unquestionable authority to govern its research. It was intended that the science plan be executed as a cooperative Federal enterprise and be coordinated with the international community. The process of creation included:

1. A workshop attended by leading active U.S. and foreign scientists. The first major workshop was that on the Carbon Cycle and Climate Impacts of Increasing CO₂ (March 1977, Miami, Florida). The second major workshop dealt with the Environmental and Societal Consequences of a Carbon Dioxide-Induced Climate Change (April 1979, Annapolis, Maryland).
2. As a result of the workshops, Research Issues are identified (a current listing of these Issues appears at the end of this note). The Research Issues are then assigned to various scientists who are asked to prepare
3. "Issue Papers." These are detailed technical plans for addressing each issue. The Issue Papers are assembled by
4. The Science Directorate into
5. The Comprehensive Plan for Carbon Dioxide Effects Research and Assessment. The Comprehensive Plan is widely distributed for
6. Review by the Science Directorate, other scientists, DOE, and other government personnel after which it was distributed to the public and to
7. Congress and the Executive as part of the budget development process.

The DOE Carbon Dioxide Research and Assessment Program is composed of seven subprograms. They are:

1. Carbon Cycle Research

The carbon cycle program's purpose is to produce a method to estimate future levels of atmospheric CO₂, given various estimates of fossil fuel consumption and any other of man's activities that could influence the CO₂ concentration. To accomplish this requires increased measurements of atmospheric and oceanic CO₂, a much better understanding of the oceanic circulation of CO₂ in all its forms, knowledge of the CO₂ absorption by natural vegetation, and the delineation of any net effects of man's disturbances of the biosphere on the carbon cycle.

2. Climate Research

The determination of the effects elevated concentrations of CO₂ will have on the global climate requires the development of more sophisticated numerical models of the climate system. These models must include more realistic geography and the incorporation of more of the feedbacks in the natural system.

The reconstruction of past climates is important not only to give some clues to what is possible in the future, but to provide data for the evaluation of the simulation models.

3. Effects of Climate Change and CO₂ Increase on the Environment

This area includes research on the changes in the environment caused by induced climate change due to increasing atmospheric concentrations of carbon dioxide.

4. Societal Impacts of Environmental Change

This area addresses economic, political, and social impacts of environmental changes.

5. Amelioration and Adaptation

Included in this category is research dealing with strategies or technological fixes for minimizing rates of carbon dioxide increase and, also, with strategies or technological initiatives for adapting the global societal system to a new environmental state.

6. Assessment

A program to determine (a) the environmental, economic, political, and social costs/benefits resulting from increasing carbon dioxide and (b) the determination of whether the research effort is properly oriented toward the goal.

7. Program Development

This category includes funding for activities for developing the DOE and national research programs and the assessment program.

In 1984 and 1989, a comprehensive, authoritative assessment report will be issued. The assessment report will represent an international consensus of the perceived costs or benefits of the carbon dioxide issue and the confidence that can be placed in those estimates. In addition, the first of these reports will determine the effectiveness of the international research program and will recommend appropriate research reorientations.

In FY 1978, funding for the CO₂ program was \$1,500,000 and in FY 1979 \$3,000,000. The FY 1980 level is expected to be \$6,000,000.

During mid-1979, the U.S. National Climate Program Office created an Interagency Committee on Carbon Dioxide and Climate. Chaired by the Department of Energy, this Committee will facilitate further coordination of all of the ongoing carbon dioxide research in the United States.

RESEARCH ISSUES (8/23/79)

THE NATIONAL CARBON DIOXIDE EFFECTS RESEARCH AND ASSESSMENT PROGRAM

I CARBON DIOXIDE

A. Net Sources of CO₂

1. Industrial Sources
2. Terrestrial Sources
3. Oceanic and Cryospheric

B. Atmospheric Storage

1. Observation of Atmospheric CO₂

C. Sinks for CO₂

1. Air-Sea Transfer of CO₂
2. CO₂ Exchange between Upper and Deep Ocean
3. Ocean Sediments (and other sinks?)
4. Biospheric Sinks

D. Historical Records of CO₂

E. Models of the Carbon Cycle

II CLIMATE

A. Climate Scenario Development

B. Reconstruction of Past Climates

C. Climate Models

D. Evidence of Climate Change

III ENVIRONMENTAL EFFECTS OF CLIMATE CHANGE AND CO₂ INCREASE (TENTATIVE)

A. General

1. Development of climate scenarios and their use in evaluating impacts.

B. Effects on Oceans and the Oceanic Cryosphere

1. Physical oceanography. Effects of climate change on the mixed layer, currents, upwelling, bottom formation, and on chemical composition.

2. Effects of chemical and physical changes on primary production and the marine food web. Changes in nutrients, pH, and salinity. Effects on estuaries and on fish and other food production.
 3. Effects on sea ice, ice shelves, and sea level with particular reference to West Antarctica, and reconstruction of historic analogs for such changes
- C. Effects on the Terrestrial Biosphere
1. Effects on the terrestrial biosphere including wildlife, pests, pathogens and fire
 2. Response of terrestrial ecosystems, including growth yield and composition in tundra, grasslands, boreal-temperate-tropical forests and savanna
 3. Effects on plant morphology, phenology and reproduction
 4. Effects on photosynthetic efficiency and biomass production
 5. Effects on plant water use efficiency
 6. Effects on soil organic matter
 7. Effects on soil moisture and management of freshwater resources
 8. Effects on growing seasons, and land clearing and cropping patterns
 9. Adaptation by development of new agricultural crop, rangeland species, and forest tree genotypes

IV SOCIETAL EFFECTS (TENTATIVE)

- A. Perception by a spectrum of decision units of information on CO₂
- B. Socioeconomic implications of preventive, curative and adaptive strategies
- C. Past climatically-induced social and economic impacts and their use as analogs of modern impacts, and identification of most effective adaptive strategies
- D. Migration and demographic shifts as a response to climate change
- E. Effects on international food resources and reserves
- F. Adaptation of socioeconomic systems to varying rates of exogenous change, including climate change

- G. Implications of unilateral, multinational, and international action in response to climate stress

V AMELIORATION AND ADAPTATION

- A. Preventative Measures
- B. Curative Measures
- C. Adaptive Measures

VI ASSESSMENT

- A. 1984 Assessment Report Preparation
- B. Support Functions
- C. Scenario Development

VII PROGRAM DEVELOPMENT

Charge Slips - Technical Reports

Publishing Body Canada

Atmospheric Env't.

Report Number Carbon Dioxide

Title Issues & Impacts.

RESOURCE CENTRE
INST. FOR ENVIORN'L. STUDIES
UNIVERSITY OF TORONTO



